TAMPERE UNIVERSITY OF TECHNOLOGY
Degree Programme in Information Technology

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Relative Positioning of Mass Market Devices in Indoor Environments

Master of Science Thesis

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ABSTRACT

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Recently, people are demanding more and more social, ubiquitous and cognitive features on their smart phones to enhance communication and interactions between users. Indoor relative positioning technology provides potential to develop such applications. Several of projects and products of positioning systems have been carried out with different positioning technologies through past few years to demonstrate their potential features and abilities.

The object of this thesis is to study and develop a practical relative positioning solution based on received signal strength measurement for locating neighbouring mass market mobile devices using passive scanning. Thus, we have implemented a python application for Linux-based mobile devices to demonstrate features and solutions.

The results of the proposed positioning technique show it is feasible for implementing a practical relative-positioning application. Experiments have been carried out successfully to demonstrate the positioning technique with up to five heterogeneous devices in short range.

PREFACE

This Master of Science Thesis, “Relative positioning of mass market devices in indoor environments”, has been carried out in the Department of Computer Systems (DCS), Tampere University of Technology (TUT), Tampere, Finland. The research work for this thesis has been done during the years 2010-2011 at the DCS GNSS Receiver Group, Tampere University of Technology.

I would like to express my gratitude to my thesis examiner, Professor Jari Nurmi for supporting me to complete my Master of Science Thesis. I would also especially thank for my supervisor and examiner, Francescantonio Della Rosa, for his time to help me in my thesis guidance.

I am thankful to Yuan Song from Tianjing Foreign Studies University for her kind encouragement throughout my studies.

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CONTENT

ABBREVIATIONS

AOA	Angle of Arrival
AP	Access Point
BS	Base Station
BSA	Basic Service Area
BSS	Basic Service Set
DS	Distribution System
ESS	Extended Service Set
GPS	Global Positioning System
IP	Internet Protocol
LAN	Local Area network
LBS	Location-based Services
LS	Least Square
MAC	Media Access Control
MS	Mobile Station
NFC	Near Field Communication
NLOS	Non-line-of-sight
P2P	Peer-to-peer
PL	Path-loss
RFID	Radio Frequency Identification
RSS	Received Signal Strength
RSSI	Received Signal Strength Syndication
SSID	Service Set Identifier
TOA	Time of Arrival
TDOA	Time Difference of Arrival

UTM	Universal Transverse Mercator
WLAN	Wireless Local Area Network

1 INTRODUCTION

Recently, people are demanding more and more social, ubiquitous and cognitive features on their smart phones, thus applications having features like social media sharing and social information exchanging applications [5][32][33] have been implemented through past few years. Indoor positioning techniques become significantly useful to improve those applications for both enhancing functionalities and expanding in business area [6].

Differently from absolute localization systems [39] such as Wireless Sensor Networks (WSNs) and Access Point in WLAN adopted to obtain localization information from known fixed reference points, relative positioning can be performed in scenarios without a fixed infrastructure. It gives a relative localization in a defined area (such as office rooms, classrooms, etc.) where it is usually possible to connect target devices using WLAN ad-hoc network [2] which allows users to communicate [3].

Relative positioning provides interesting features to mobile devices, letting them to know their position in relation to other devices nearby and allowing the enhancement of multi-devices and multi-user interactions [4].

In this thesis we present an experimental approach to relative positioning on heterogeneous mass market devices exploiting Received Signal Strength (RSS) measurements obtained from nearby mobile devices connected in WLAN ad-hoc mode. A Python application running on Linux-based Operative Systems has been implemented to obtain a radar view of the estimated positions of the mobile devices.

1.1 Objective

The aim of this thesis is to study and implement a practical relative positioning solution based on RSS for locating neighbouring mass market mobile devices using passive scanning. Experiments using a Python application on Nokia N900 mobile phones have been carried out to prove the feasibility of methods and algorithms used in the research work.

2 PROJECT DESCRIPTION

In this chapter, a brief background of the project including scenarios, problem definitions and project scope will be introduced.

2.1 Introduction

In the thesis, we present an experimental approach to the relative positioning of heterogeneous mass market devices in ad-hoc WLAN technology based on RSS measurements. One application implemented on Nokia N900 to detect the spatial placement of the neighbouring devices justifies the feasibility of our approach and shows potential usage for future works. Figure 1 shows the practical situation where our technology could be applied for.

Figure 1 Practical scenario of relative positioning

2.2 Scenario

The scenario of the experiments takes place in a typical classroom as shown in Figure 2. The scope is to estimate the relative positions of several heterogeneous devices placed around the user. For all the experiments we have used the following mass market devices: two Nokia N900 (referring as MS0 and MS4), two NOKIA N810 (referring as MS1 and MS2), and two laptops ASUS X51L Series (referring as MS3 and MS5) with Atheros AR928x Wireless Network Adapter.

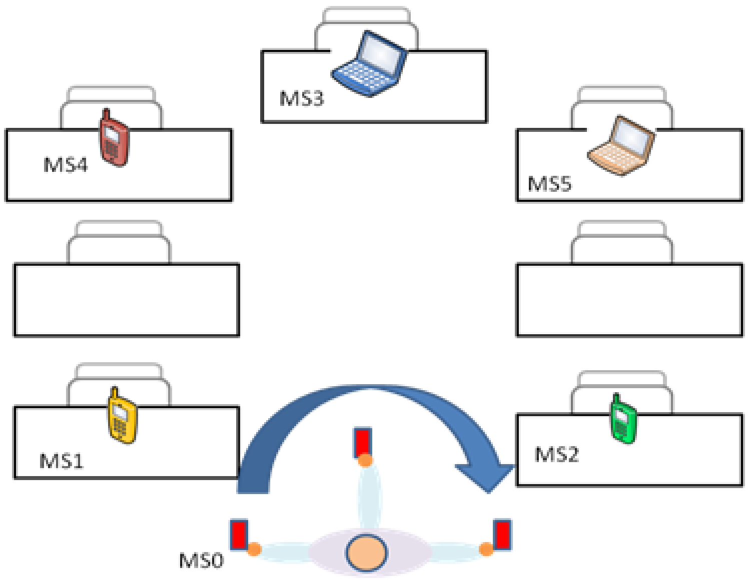

Figure 2 Scenario of the experiments

2.3 Problem definition

The first challenge of our work is to use radio signal to determine the relative position of nearby mobile devices in WLAN ad hoc networks for indoor environment. Accuracy of localization is relying on the quality of the RSS, such as no blocking by human body or obstacle in the environment.

In our scenarios, a Least Square (LS) algorithm with RSS measurements is exploited to compute the relative localization of nearby devices on a Nokia N900.

The situation is described as follows: MS0 wants to know the relative positions of the nearby devices placed around; WLAN ad-hoc network is the only technology that is available, since common to all the adopted devices; all the devices are connected in the ad-hoc network; results will be displayed on MS0's screen as a map of estimated positions of others.

The application, implemented in Python, is used to measure and log RSS information; convert RSS into estimated distance by calibrating a path-loss model; besides, it will perform relative positions estimation by applying Least Square algorithm; moreover, it stores the RSS information as data for post-processing and analysis with Matlab.

2.4 Scope of the project

The purpose of this project is to provide a solution to perform relative positioning on mass market mobile devices through ad-hoc WLAN network by acquiring RSS information. The key point of the research work is to study the behaviours of RSS in different scenarios.

The following list summarizes the focuses of the project:

- To study positioning techniques using RSS
- To study and analyze RSS behaviour in various scenarios
- To develop an application for relative positioning on mass market mobile devices

2.5 Assumptions

Some assumptions have to be considered in order to simplify the complexity of the problem proposed in this research work:

- All the MSs are using the same path-loss model.
- All the MSs are in Line of Sight (LOS) with each others.

3 BACKGROUND THEORY

In this chapter, background theory of positioning methodology will be discussed. Basically, there are three types of general classification of positioning techniques [9]:

- Network-Based: BSs in the network perform estimation of measurements and computation of a location position.

- Mobile-Based: MSs perform estimation of measurements and computation of a location position.

- Mobile-Assisted: MSs provide position measurements to the network, which will perform computations for location estimate.

Based on the aforementioned classifications, four major techniques for localization can be derived, which are AOA (arrival of angle), TOA (time of arrival), TOA (time of arrival) and RSS Measurement (Received Signal Strength).

3.1 Positioning techniques

- AOA technique:

  The RF sensor measures the direction of the received signal transmitting from the target. The final position can be determined by using triangulation methods while obtaining at least three angles from different fixed targets. The AOA is considered mainly for outdoor positioning using Base Stations (BSs) of cellular networks [10], but results on AOA positioning in WLAN infrastructure have also been reported [42]. Reflections and non-line-of-sight (NLOS) conditions highly distort the direction of arrival of the signals, deteriorating the accuracy of AOA positioning [8].

- TOA technique:

  Positioning methods based on TOA evaluate the distance by estimating the signal propagation.

  As the time duration of the signal travelling from the transmitter to the receiver is associated with the distance between them, thus, distance between the receiver and transmitter can be calculated by the following equation where c stands for the speed of light:

Distance=c*Time.

TOA measurements need to use at least three reference stations in different locations for trilateration.

- TDOA technique:

TDOA measurements can be estimated by performing the cross-correlation between two received signals [11]. The TDOA system determines the mobile phone position based on trilateration, as shown in Figure 3. Differently from TOA, this technique uses time difference measurements rather than absolute time measurements. It is often referred to as the hyperbolic system because the time difference is converted into a constant distance difference between two base stations (as foci of the hyperbola) to define a hyperbolic curve [12]. Therefore, at least three BSs are used for positioning with the intersection of hyperbolas in 2-D case.

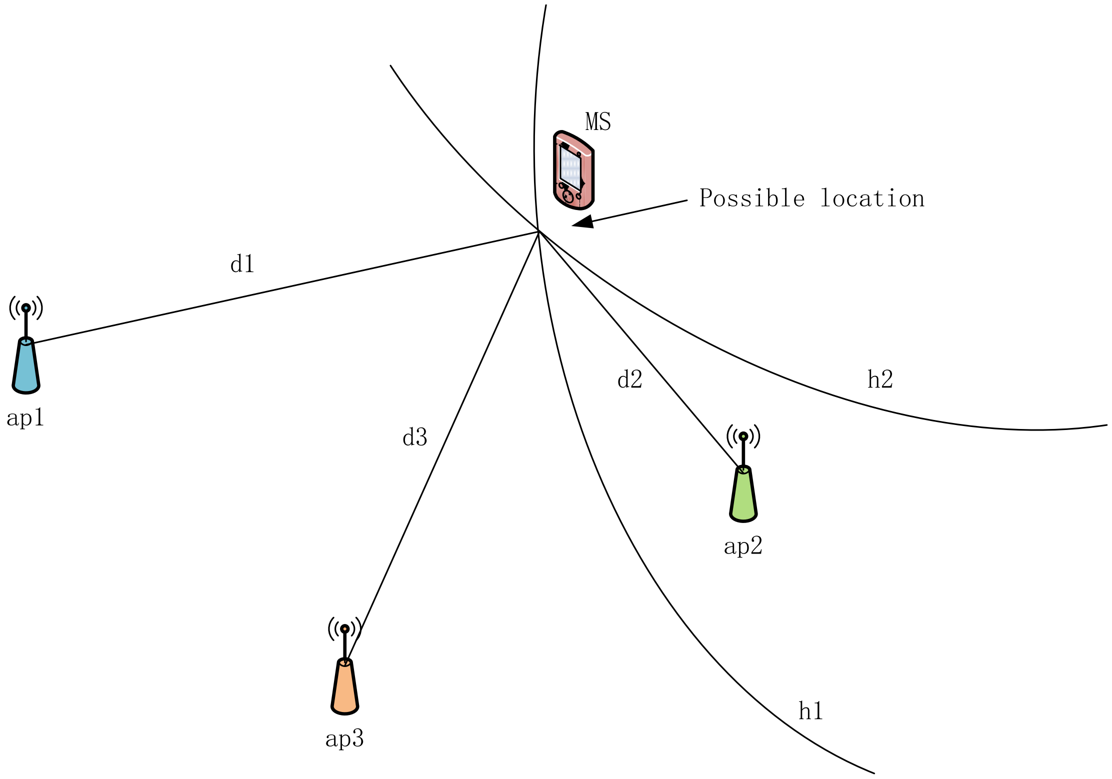

Figure 3 TDOA measurement

- RSS Measurement (Received Signal Strength):

RSS measurement is based on the principle that the signal strength/power decays proportionally to the distance between the transmitter and receiver. The RSS information can be simply converted into distance by using a theoretical or empirical pass loss model. According to [13], when applying triangulation the distance measurements from at least three APs with known positions are needed to estimate the final location. Figure 4 shows the positioning method based on RSS measurements.

RSS-based techniques have a low complexity and cost among the alternatives since RSS measurement is readily available in most of the wireless systems [43]. However, the accuracy of estimating is heavily relying on several parameters such as signal fluctuations, path loss model and depending on the environment such as LOS (Line Of Sight) channel and multipath effects.

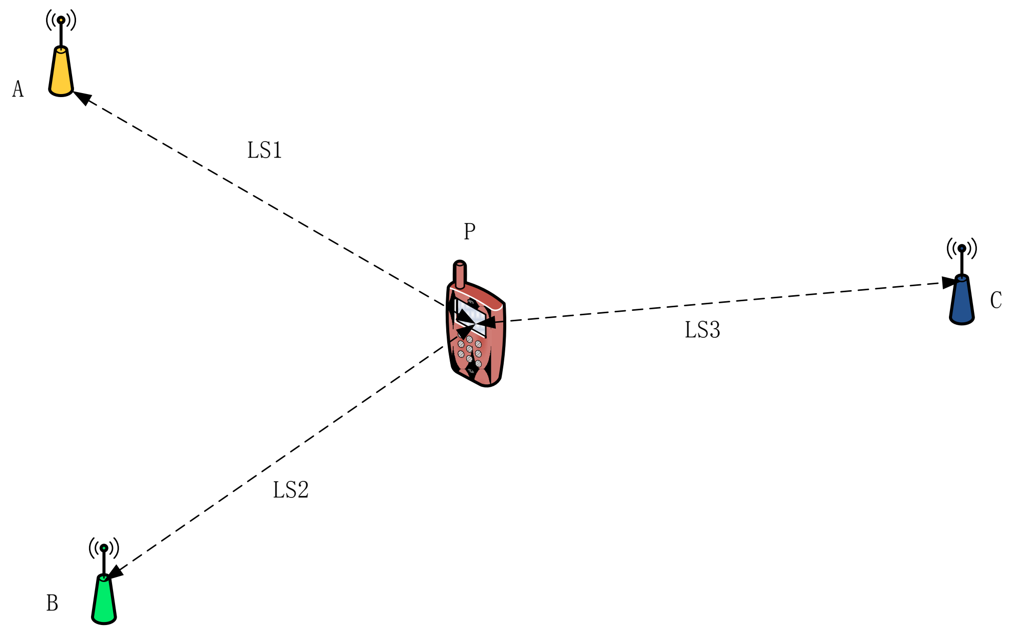

Figure 4 RSS Measurement

3.2 Least square Algorithm

After the MS has obtained the RSS measurements, they are then converted into a set of circular equations, from which the target MS position can be determined with the knowledge of other MSs geometry [17].

Using non-linear equations in [18] is a straightforward approach to determine the MS position with measurements directly. Another approach [20]–[21] to avoid using direct methodology is to linearize the measurements. The result can be found iteratively; but the preciseness is relying heavily on the precision of initial estimation.

A least square algorithm has been implemented [21] to solve over-determined or inexact equation of the system in an approximate way by minimizing the sum of the squares of the residuals instead of solving the exact results of the equation [22]. This algorithm has its advantage of easy solution to have a fast computation on heterogeneous mobile devices.

The following equations represent the main procedure used for five mobile stations localization [21]:

$$(r^{(i)[1]})^2 = (x^{[1]} - \hat{x}^{(i)})^2 + (y^{[1]} - \hat{y}^{(i)})^2$$

$$(r^{(i)[2]})^2 = (x^{[2]} - \hat{x}^{(i)})^2 + (y^{[2]} - \hat{y}^{(i)})^2$$

$$(r^{(i)[3]})^2 = (x^{[3]} - \hat{x}^{(i)})^2 + (y^{[3]} - \hat{y}^{(i)})^2$$

$$(r^{(i)[4]})^2 = (x^{[4]} - \hat{x}^{(i)})^2 + (y^{[4]} - \hat{y}^{(i)})^2$$

$$(r^{(i)[5]})^2 = (x^{[5]} - \hat{x}^{(i)})^2 + (y^{[5]} - \hat{y}^{(i)})^2$$

where $r^{[i][j]}$ is representing the distance between centre MS_i and other nearby MS_j. By defining $(k^{[j]})^2 = (x^{[j]})^2 + (y^{[j]})^2$, the previous equation could be re-written as following format:

$$\left(\hat{\Delta}^{(i)[2]} + r^{(i)[1]}\right)^2 = \left(k^{[2]}\right)^2 - 2x^{[2]}\hat{x}^{(i)} - 2y^{[2]}\hat{y}^{(i)} + \left(r^{(i)[1]}\right)^2$$

$$\left(\hat{\Delta}^{(i)[3]} + r^{(i)[1]}\right)^2 = \left(k^{[3]}\right)^2 - 2x^{[3]}\hat{x}^{(i)} - 2y^{[3]}\hat{y}^{(i)} + \left(r^{(i)[1]}\right)^2$$

$$\left(\hat{\Delta}^{(i)[4]} + r^{(i)[1]}\right)^2 = \left(k^{[4]}\right)^2 - 2x^{[4]}\hat{x}^{(i)} - 2y^{[4]}\hat{y}^{(i)} + \left(r^{(i)[1]}\right)^2$$

$$\left(\hat{\Delta}^{(i)[5]} + r^{(i)[1]}\right)^2 = \left(k^{[5]}\right)^2 - 2x^{[5]}\hat{x}^{(i)} - 2y^{[5]}\hat{y}^{(i)} + \left(r^{(i)[1]}\right)^2$$

After manipulating the previous equations, a new set of functions have been obtained:

$$-x^{[2]}\hat{x}^{(i)} - y^{[2]}\hat{y}^{(i)} - \hat{\Delta}^{(i)[2]}r^{(i)[1]} = \frac{1}{2}\left(\left(\hat{\Delta}^{(i)[2]}\right)^2 - \left(k^{[2]}\right)^2\right)$$

$$-x^{[3]}\hat{x}^{(i)} - y^{[3]}\hat{y}^{(i)} - \hat{\Delta}^{(i)[2]}r^{(i)[1]} = \frac{1}{2}\left(\left(\hat{\Delta}^{(i)[3]}\right)^2 - \left(k^{[3]}\right)^2\right)$$

$$-x^{[4]}\hat{x}^{(i)} - y^{[4]}\hat{y}^{(i)} - \hat{\Delta}^{(i)[2]}r^{(i)[1]} = \frac{1}{2}\left(\left(\hat{\Delta}^{(i)[4]}\right)^2 - \left(k^{[4]}\right)^2\right)$$

$$-x^{[5]}\hat{x}^{(i)} - y^{[5]}\hat{y}^{(i)} - \hat{\Delta}^{(i)[2]}r^{(i)[1]} = \frac{1}{2}\left(\left(\hat{\Delta}^{(i)[5]}\right)^2 - \left(k^{[5]}\right)^2\right)$$

From which $\hat{x}^{(i)}$ and $\hat{y}^{(i)}$ can be derived:

$$H = \begin{bmatrix} x^{[2]} & y^{[2]} & \hat{\Delta}^{(i)[2]} \\ x^{[3]} & y^{[3]} & \hat{\Delta}^{(i)[3]} \\ x^{[4]} & y^{[4]} & \hat{\Delta}^{(i)[4]} \\ x^{[5]} & y^{[5]} & \hat{\Delta}^{(i)[5]} \end{bmatrix}$$

$$
\mathrm{d} = \frac{1}{2}\begin{bmatrix} \left(\hat{\Delta}^{(i)[2]}\right)^2 - \left(k^{[2]}\right)^2 \\ \left(\hat{\Delta}^{(i)[3]}\right)^2 - \left(k^{[3]}\right)^2 \\ \left(\hat{\Delta}^{(i)[4]}\right)^2 - \left(k^{[4]}\right)^2 \\ \left(\hat{\Delta}^{(i)[5]}\right)^2 - \left(k^{[5]}\right)^2 \end{bmatrix}
$$

$$
\mathrm{P} = \begin{bmatrix} \hat{x}_{est}^{(i)} \\ \hat{y}_{est}^{(i)} \\ r_{est}^{(i)[1]} \end{bmatrix}
$$

$$
\mathrm{P} = \mathrm{H}^{-1}\mathrm{d}
$$

Where $\hat{x}_{est}^{(i)}$ and $\hat{y}_{est}^{(i)}$ represent the estimated location coordinates of the centered MS and $r_{est}^{(i)[1]}$ represents the estimated distance between the centered MS and nearby MS_i [21].

3.3 Theoretical and Empirical path-loss

RSS measurements are based on the principle that the signal strength/power decays proportionally to the distance between the transmitter and receiver, thus, finding the most compatible and suitable path-loss model becomes significant in our work.

3.3.1 Theoretical path-loss

The relationship between RSS value and distance is influenced by a large number of unreliable factors [23]. The factors that affect RSS values are the multipath or fast fading factor and the shadowing or slow fading factor [23]. These two factors can be modelled with Rayleigh or Rician and log-normal distributions [24][25]. However, the fast fading term can be cleared up by obtaining the average value of RSS over a time interval [26].

The following derivation steps [27] show that the RSS values can be modelled by the following expression:

$$
P_{R_i} = P_{ref} - 10n_i \log_{10}(d_i) + X
$$

where d_i is the reference distance between two MSs. P_{ref} is the power level measured on BS from MS which depends on several factors: averaged fast and slow fading, antennas gains, and transmitted power. The term n_i represents the path-loss exponent corresponding to the path connecting the transmitter and the receiver. Parameter X denotes a zero mean Gaussian random variable caused by slow fading. This expression has been widely used [27] to describe RSS values as a function of the distance between two nodes. If we get rid of parameter X, distance can be calculated by the following equation:

$$\acute{d}_{RSS_i} = 10^{(P_{ref} - \overline{P_{R_1}})/10n_i}$$

3.3.2 Empirical path-loss

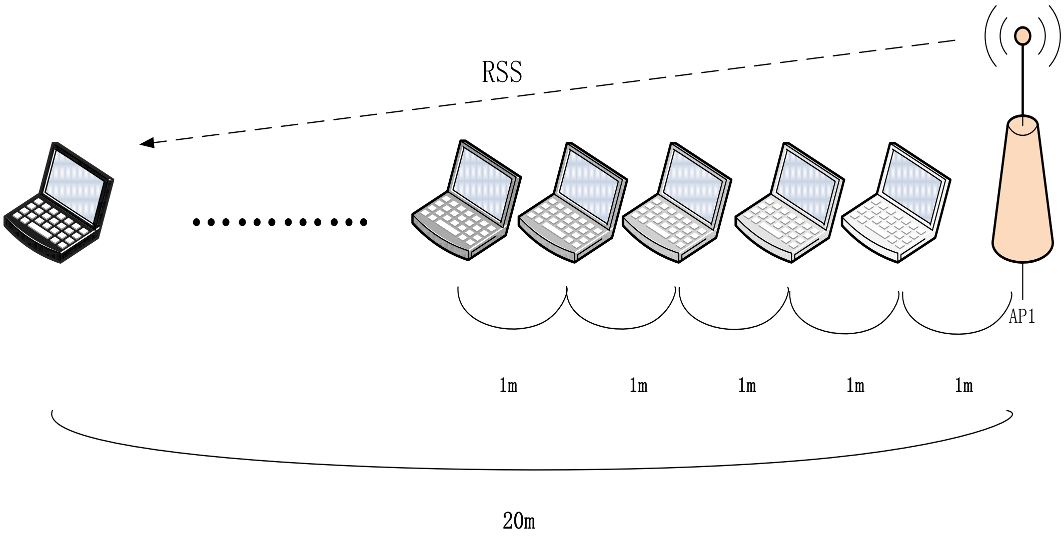

Figure 5 Obtaining RSS Information

In our project, an empirical path-loss is not determined by a theoretical model found in literature, but relying on real path-loss experiments. The path-loss model is obtained by increasing distance from 1m to 20m between two MSs which are connected in WLAN ad-hoc mode and getting the most occurring value of RSS at each step (as shown in Figure 5). Figure 6 shows the obtained empirical path-loss model (in blue) and the filtered version of it smoothed with a 4th order polynomial approximation (in red).

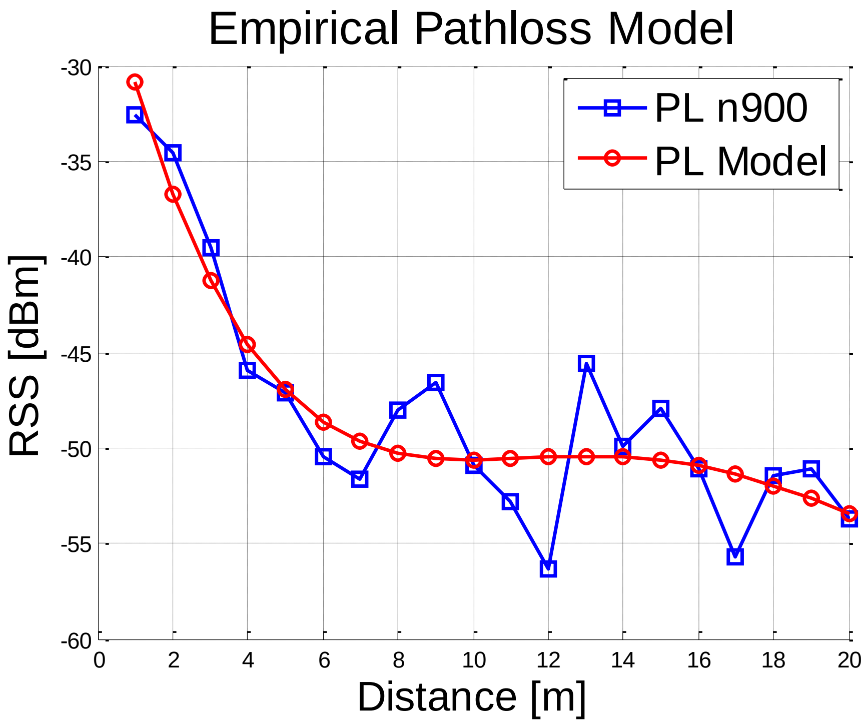

Figure 6 Empirical Path-loss Model

4 THE RELATIVE POSITIONING SYSTEM

In this section, we will introduce several related positioning systems with different kind of technologies. Then we will take an inside view of WLAN ad-hoc network and the communication protocol of our solution.

4.1 Related work

In both mass market and literature, different technologies for relative positioning have been proposed during the years. Several solutions are related to multi-hop measurements in wireless networks and several researches based on simulations have been proposed using a huge number of nodes [28]. However, literature studies usually do not apply in practical real-life scenarios. Moreover, most of the proposed studies require additional equipment or information which is not easy to implement on heterogeneous mass market devices. Some other studies propose combined technologies and sensors such as Bluetooth, ultrasound or antenna arrays for peer-based localization especially in wireless sensor networks (WSNs).

On the other hand, several proposed solutions define the proximity of pairs of devices and estimate distances between couples of neighbours placing them in virtual maps [33].

The NearMe [30] project is based on proximity-based schemes [29] which detect devices that are in a defined range among each others. An external server for computing the estimation of the location is required for this case.

BlueHoo [31] makes use of Bluetooth discovery to detect devices within the range achieved by such technology.

BeepBeep [33] is based on an acoustic ranging system with high-level of accuracy. However, the performance relies on environment noise strength which might be not suitable for deploying in public area.

Relate [32] is a successful project based on ultrasound localization, thus additional equipment such as the ultrasound hardware is required, bringing the high complexity and cost for building and utilizing such a system.

Virtual Compass [33] uses Wi-Fi and Bluetooth to detect nearby mobile devices relaying on multi-hop communications to reduce the error in distance estimation.

It is worth mentioning that all the aforementioned solutions and approaches require additional information or need a huge amount of data exchange and communication or cost huge amount of power, but only could provide uncompetitive results for example a 2-D map with few devices.

To avoid massive data exchange and provide a more general practical approach for current and future mass market devices we propose a simple peer-based method working on general Linux based mobile devices that:

- Works in both outdoor and indoor environment;
- is based on standard ad-hoc WLAN networks;
- has a fast and efficient algorithm;
- is easy to be implemented on multiple platforms;
- is able to locate several nodes simultaneously;
- does not require additional hardware

4.2 Inside the standard WLAN Ad-hoc

An ad-hoc wireless network links two or more devices having wireless communications and networking capability. Such communication protocol provides a way for one node to communicate with other nodes within their radio range [26].

WLAN technologies have been developed and upgraded for decades and there have been several different branches. However, most of the WLAN products nowadays are all based on IEEE 802.11 standard [35].

In IEEE 802.11 [36], distribution services can be accessed by an AP within a wireless link. The basic service area (BSA) is the area covered by one AP. The basic service set (BSS) is a set of wireless terminals controlled by one AP. The distribution system (DS) creates an extended service set (ESS) by connecting a set of BSSs in the wired infrastructure. A wireless terminal is able to roam freely within an ESS with the help of the IEEE 802.11 distribution services which also allow an 802.11 WLAN to connect to the wired LAN infrastructure. The IEEE 802.11 standard also defines a portal as a logical point at which non-802.11 packets enter an ESS.

There are two network topologies defined in IEEE 802.11 reference architecture: one is infrastructure network; the other one is ad-hoc network which we used in the project. In infrastructure network, wireless devices are connected with a backbone network typically attached with other wired devices such as desktops, printers and servers. Wireless APs re usually tied with infrastructure network to provide a connection between wireless terminal and wired backbone acting like a bridge. On the other hand, ad-hoc topology does not have a wired backbone, but wireless terminals can communicate directly on a peer-to-peer basis. Figure 7 illustrates the two of the topologies.

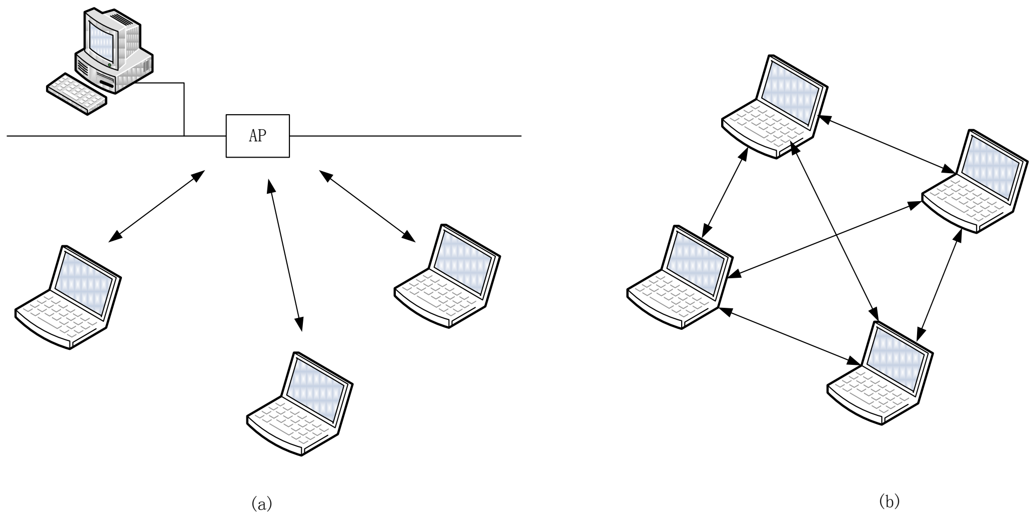

Figure 7 IEEE 802.11 network configuration: (a) infrastructure network; (b) ad-hoc

Fig. 8 (a) and Fig. 8 (b) describe two variations of the peer-to-peer network topology. In Figure 7(a), every user terminal is able to communicate directly with any other user terminal. Multi-hops meshed networks are described in Fig.8 (b). It is used when the users are distributed over a certain distance that the users could not reach all the terminals in the network.

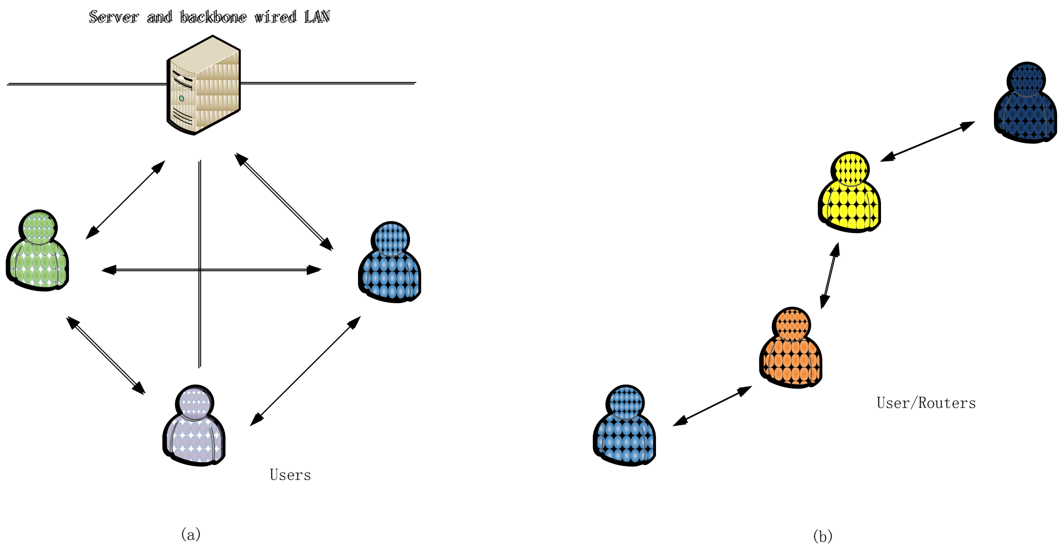

Figure 8 Two different types of network protocols

In ad-hoc mode, the network is reconfigurable and can operate without the need for a fixed infrastructure which is referred as distributed-network topology. It could provide either single-hop or multi-hop connectivity since 802.11 WLAN standard supports both of the modes.

Since it is easy and direct for connecting different devices, this project can explore the problem of localization service occurring in ad-hoc WLAN networks by simply measuring the RSS from neighbouring devices.

4.3 System Architecture

Figure 9 shows the system architecture. In the experiments of the project, all MSs are able to set up their own single-hop ad-hoc network based on the IEEE 802.11. In order to set up the scenario for indoor environment, MSs are placed in a typical classroom. All the MSs are connected in ad-hoc mode within LOS conditions. After that, one MS (specifically MS0) starts to measure all the RSS coming from each radio link simultaneously.

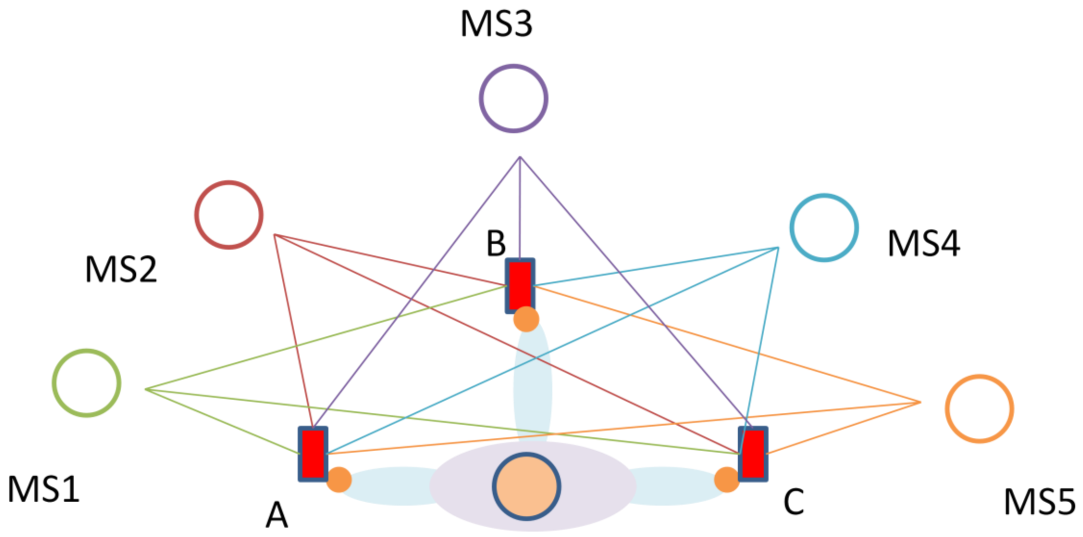

Figure 9 Five devices experiment scenario

In Figure 10, a communication protocol is proposed when one MS (in the centre) wants to know the relative positions of other MSs nearby. At the beginning, all the MSs are connected in the ad-hoc network that make sure the packets in the network could be detected by the centred MS. The process is mainly divided into two parts. In the first stage, MS0 will record all the RSS information from the rest MSs by placing on three different coordinates for a certain time interval. As a result, a set of three RSS measurements are obtained. After MS0 has collected the RSS measurements, it will perform localization by applying empirical path-loss model and least square algorithm on itself. Finally, the results of coordinates of three devices will be displayed.

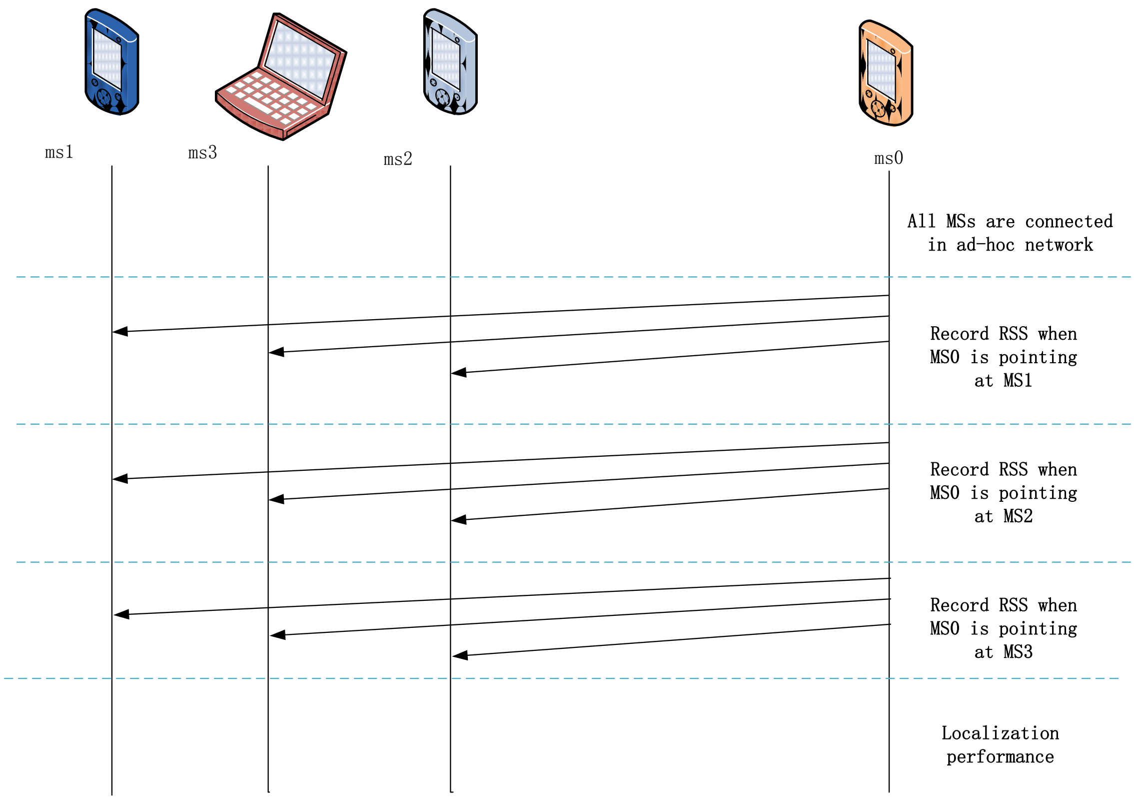

Figure 10 System communication protocol

5 APPLICATION ON MASS MARKET DEVICES

In this chapter, the python application implemented for the project is introduced with different sets of experiments.

5.1 RSS for heterogeneous devices

In heterogeneous mass market mobile devices such as laptops and smart-phones, the levels of the measured RSS from device to device usually are conspicuously different due to massive producer and fabric technology in wireless card.

In our project, three different devices have been used for complex scenarios, thus it is required to extensively analyse devices in order to get specific RSS information and derive path-loss models for heterogeneous mass market devices.

The experiments results are taken by one N900 while the target devices are connected in ad hoc mode. In Figure 11, three curves of path-loss have been plotted.

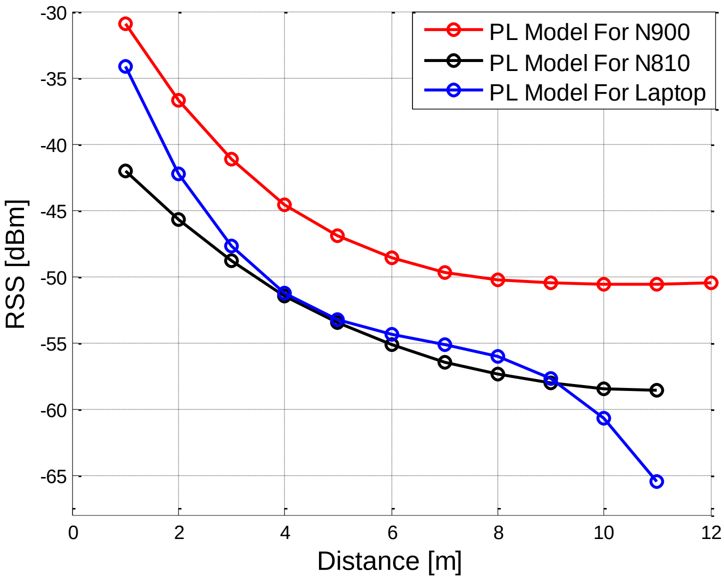

Figure 11 Three path-loss models

We can see the differences among heterogeneous devices, however, the behaviours of the curves are quite the similar, especially in short range distance. Considering the indoor environment and scenarios such as office room or classroom, it is better to use one general path loss model for all the computations in order to keep consistence and easy implementation.

5.2 Software blocks

The software application has been developed on Nokia N900 smart phone with Maemo 5 Operating System using Python scripting language. Several open source python libraries have been ported into Maemo 5, such as pygame [44] and numpy [45]. Pygame is used for designing the user interface while numpy is needed for mathematics and matrix calculations. Besides, tcpdump for Maemo has been installed in order to acquire the information of WLAN networks.

Figure 12 describes the procedure of the application:

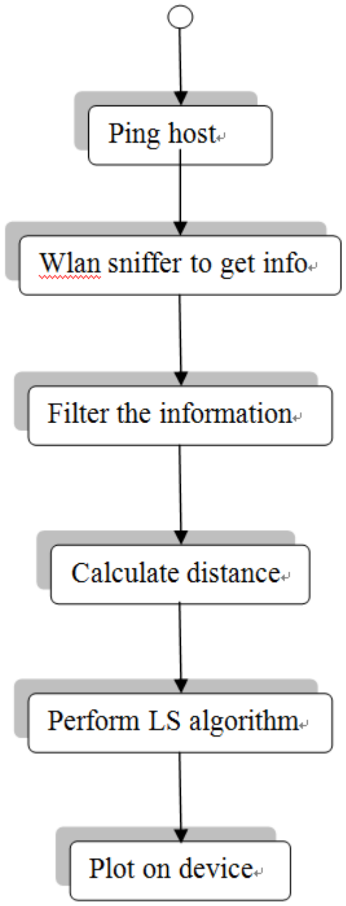

Figure 12 Application flow

Pinging the Host

The application starts with ping host module. The purpose of pinging hosts is to enable traffic data in the network, allowing the tcpdump to grab useful package information.

Acquisition of Wi-Fi Information

After there are data transferring in the network, a process with system call of tcpdump will be prepared. Tcpdump collects all possible packages transferring in the air which includes both the network we targeted and those that are not necessary. The collected information is stored in a temporary log file.

Parsing the Information

What we have now is all the package information in the air, however, the data is collected in a mass which contains 90% useless package information. This parser module is right to deal with filter keywords to obtain exact the information we need such as network card MAC address, SSID of the network as well as signal strength in dBm. After extracting from the original data file, a RSS file to the desire device will be stored.

RSS to Distance Conversion

Converting from RSS to real distance is a critical part of the project. Empirical path-loss model is described in the following formula:

$$Distance = p1 * RSS^3 + p2 * RSS^2 + p3 * RSS + p4$$

Where: p1 = -0.0068586, p2 = -0.79482, p3 = -30.514 and p4 = -385.51.

Least Square Algorithm

The least square module is introduced theoretically in the previous chapter 3.5. It is easy to achieve matrix calculation in Matlab, however, it might have some difficulties in real application, and thus, external library numpy for manipulating matrix is required.

After passing distance array calculated in get-distance module to least square function, a set of estimated coordinates of the devices will be provided.

Draw on screen

The previous results of target devices’ coordinates give us possibility to provide a friendly user interface on devices of Nokia N900. Pygame is an open source python library which could be easily ported on Maemo OS. By calling APIs from the library, estimated coordinates could be plotted. Figure 13 shows the real application running on N900. The white dot in the centre is where we are standing at. The red ones indicate three references stations when we hold mobile and move it round. The yellow, black and blue ones are the result of estimated target mobile stations.

Figure 13 Real application on Nokia N900

5.3 Experimental Scenarios

5.3.1 Three devices

5.3.1.1 Short distance

The following experiments have taken place in a typical class room with four MSs (MS0, MS1, MS2 and MS3). MS1 – MS3 are three transmitters while MS0 is charging for recording three different sets of signal strength coming from the ad hoc network.

Table 1 and table 2 are the MSs' coordinates configurations of two experiments. Figure 14 demonstrates the brief scenario of the experiments.

	ms1	ms2	ms3
Ex1	-2,1	2,1	0,2
Ex2	-3,1	3,1	0,3
Ex3	-4,1	4,1	0,4

Table 1 Three devices short range config 1

	ms1	ms2	ms3
Ex1	-2,2	2,2	0,3
Ex2	-2,4	2,4	0,5
Ex3	-2,6	2,6	0,7
Ex4	-2,8	2,8	0,9

Table 2 Three devices short range config 2

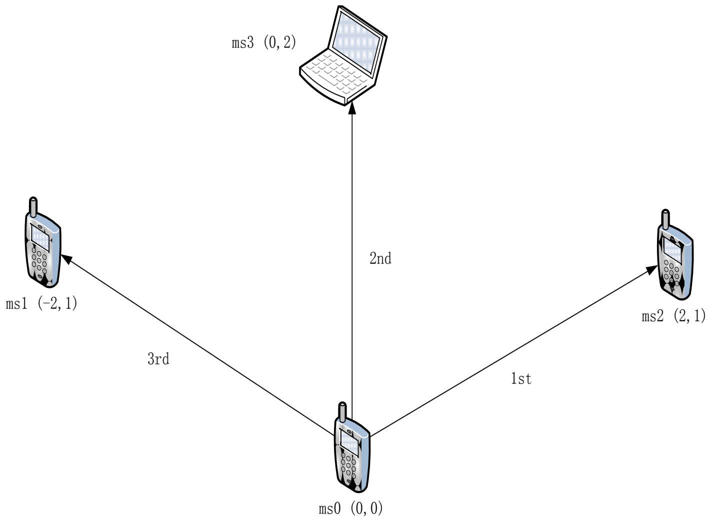

Figure 14 Three devices configuration

The procedure of the experiments is described as follows

1. Three ad-hoc networks are set up and placed in the right position.
2. MS0 is the centre of the map, the coordinate is known as (0, 0).
3. Hold MS0 in hand in coordinate (1, 0) for 100 records receiving and logging three RSS information.
4. Hold MS0 in hand in coordinate (0, 1) for 100 records receiving and logging three RSS information.
5. Hold MS 0 in hand in coordinate (-1, 0) for 100 records receiving and logging three RSS information.

5.3.1.2 Long distance

Long distance experiments are mainly the same as short ones. These experiments are taken in place in large lecture theatre so that the longest distance between two nodes could achieve 13 meters.

In Chapter 6, we will discuss more about the different between short distance and long distance behaviours in ad-hoc network relative positions.

Long distance configurations are shown in table 3 – table 5

Config I:

	ms1	ms2	ms3
Ex1	-6,2	6,2	0,3
Ex2	-6,4	6,4	0,5
Ex3	-6,6	6,6	0,7
Ex4	-6,10	6,10	0,11
Ex5	-6,12	6,12	0,13

Table 3 Long distance config 1

Config II:

	ms1	ms2	ms3
Ex1	-5,2	5,2	0,3
Ex2	-5,4	5,4	0,5
Ex3	-5,6	5,6	0,7
Ex4	-5,10	5,10	0,11
Ex5	-5,12	5,12	0,13

Table 4 Long distance config 2

Config III:

	ms1	ms2	ms3
Ex1	-3,2	3,2	0,3
Ex2	-3,4	3,4	0,5
Ex3	-3,6	3,6	0,7
Ex4	-3,10	3,10	0,11
Ex5	-3,12	3,12	0,13

Table 5 Long distance config 3

Config IV:

	ms1	ms2	ms3
Ex1	-2,2	2,2	0,3
Ex2	-2,4	2,4	0,5
Ex3	-2,6	2,6	0,7
Ex4	-2,10	2,10	0,11
Ex5	-3,12	2,12	0,13

Table 6 Long distance config 4

5.3.2 Room Experiments

In the previous experiments, we used three devices as the minimum number. A set of more practical experiments with five mobile devices are placed in this procedure. In these experiments, we simulate the situation that there are several devices in the office room or class room.

	X	Y
MS0	0	0
MS1	-2	1.5
MS2	2	1.5
MS3	0	4.7
MS4	-2	4
MS5	2	4

Table 7 Room experiment config

The configuration is shown on the above table 7. Figure 15 is the vision how the experiments are set.

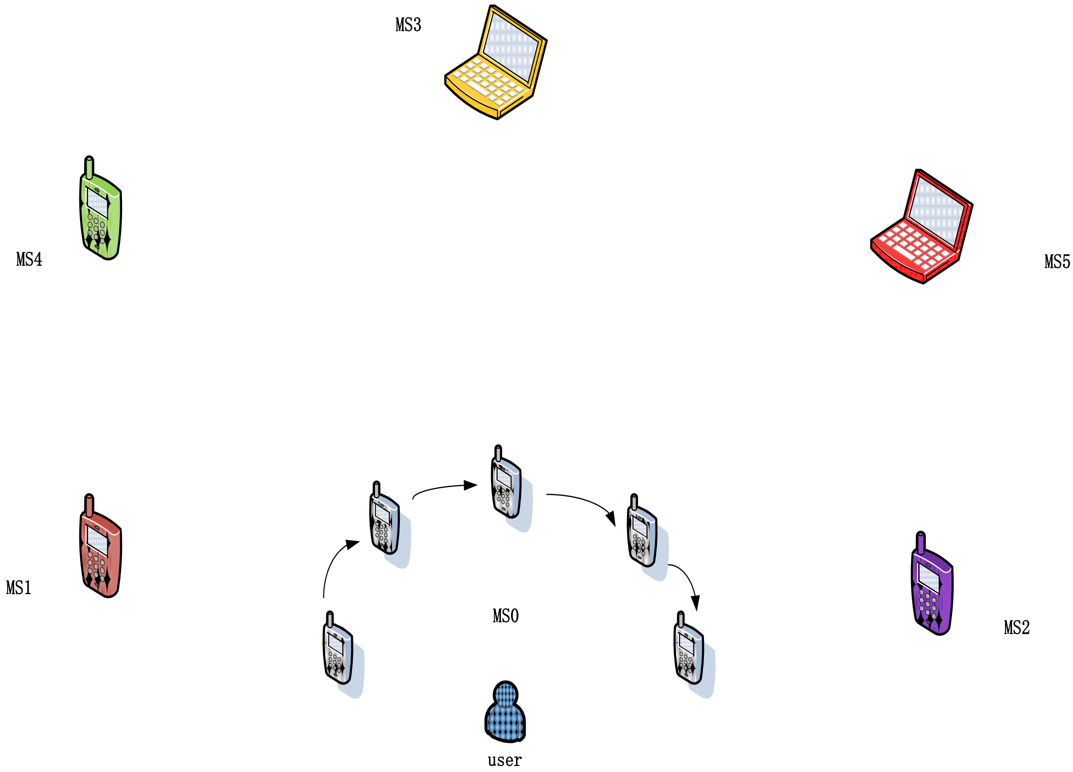

Figure 15 Five devices configuration

The procedure is now extended to detect five positions logging five different RSS in files.

1. Five devices start their own ad hoc network and are placed in the expected position.
2. MS0 is the centre of the map, the coordinate is known as (0, 0).
3. Hold MS0 in hand in coordinate (-1, 0) for 60 records receiving and logging five RSS information.
4. Hold MS0 in hand in coordinate (-0.7, 0.7) for 60 records receiving and logging five RSS information.
5. Hold MS0 in hand in coordinate (0, 1) for 60 records receiving and logging five RSS information.
6. Hold MS0 in hand in coordinate (0.7, 0.7) for 60 records receiving and logging five RSS information.
7. Hold MS0 in hand in coordinate (1, 0) for 60 records receiving and logging five RSS information.

5.3.3 Body-Loss and Hand-Grip Effect

During the experiments above, found that the human body is acting like a source causing inaccuracies and unpredictable behaviours of the measured RSS. In particular, the direction of user body absorbing the signal has attracted the research interest and has been identified as source of errors in the location estimation [40]. The results [40] indicate that the signal strength at a given location varies by up to 5 dBm depending on the direction that the user is facing. Hence, the body of the user creates a systematic source of error and introduces a constant bias in the estimated locations that, if correctly accounted, can offer a beneficial impact on the accuracy of the position.

In this set of experiments, we present scenarios when user is holding device in hand, comparing the ones measured without human body, we could conclude error between them, that we called hand-grip error. Figure 16 shows how the four cases are tested in the experiments: A (font) no obstacle between AP and MS; B (back) human body is blocking on the path between AP and MS; C (right) and D (left) show that AP is at left and right side of the user, thus, part of the path is blocked.

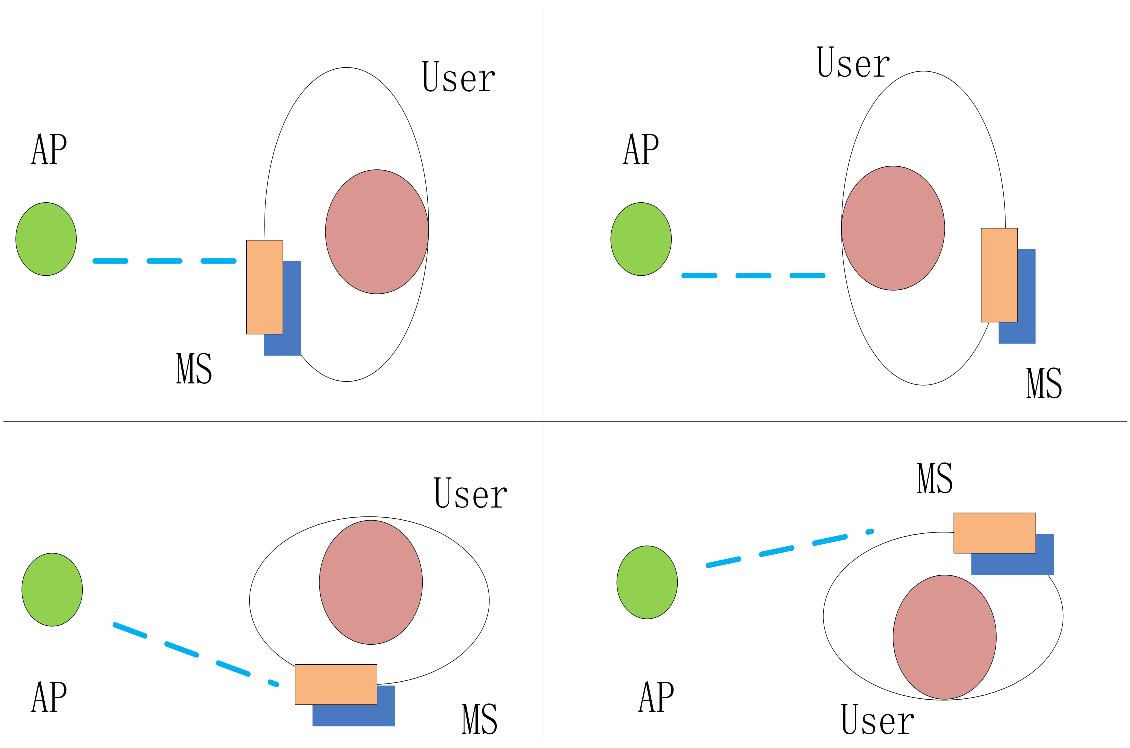

Figure 16 Body effect experiments

5.3.4 Device orientation experiments

Besides body blocking and hand grip effect mentioned before, signal strength will also be affected naturally by the orientation of the device due to where the antenna has been installed. Thus, a set of experiments with different orientations is presented to have an exploration of these different complex situations.

General mobile phones or laptops, they can be seen as cuboids. It is known that there are 6 faces in cuboids, and for each face in its 2-D plain, four sides cause four different cases. So there are 6*4 unique orientation positions for each cuboid which would probably lead to 24 level of signal strength in one particular distance. In the experiments, however, we do not need all the results from all of the 24 aspects, but have chosen 10 representative orientation positions that are used often in real life.

The procedure of the experiments is simple. One laptop setup an ad hoc network, hold the mobile device in one orientation position (not covering the antenna) in distance of 1 meter, 3 meter and 5 meter recording 60 logs for each.

Figure 17 shows the 10 different orientation positions used in the experiments

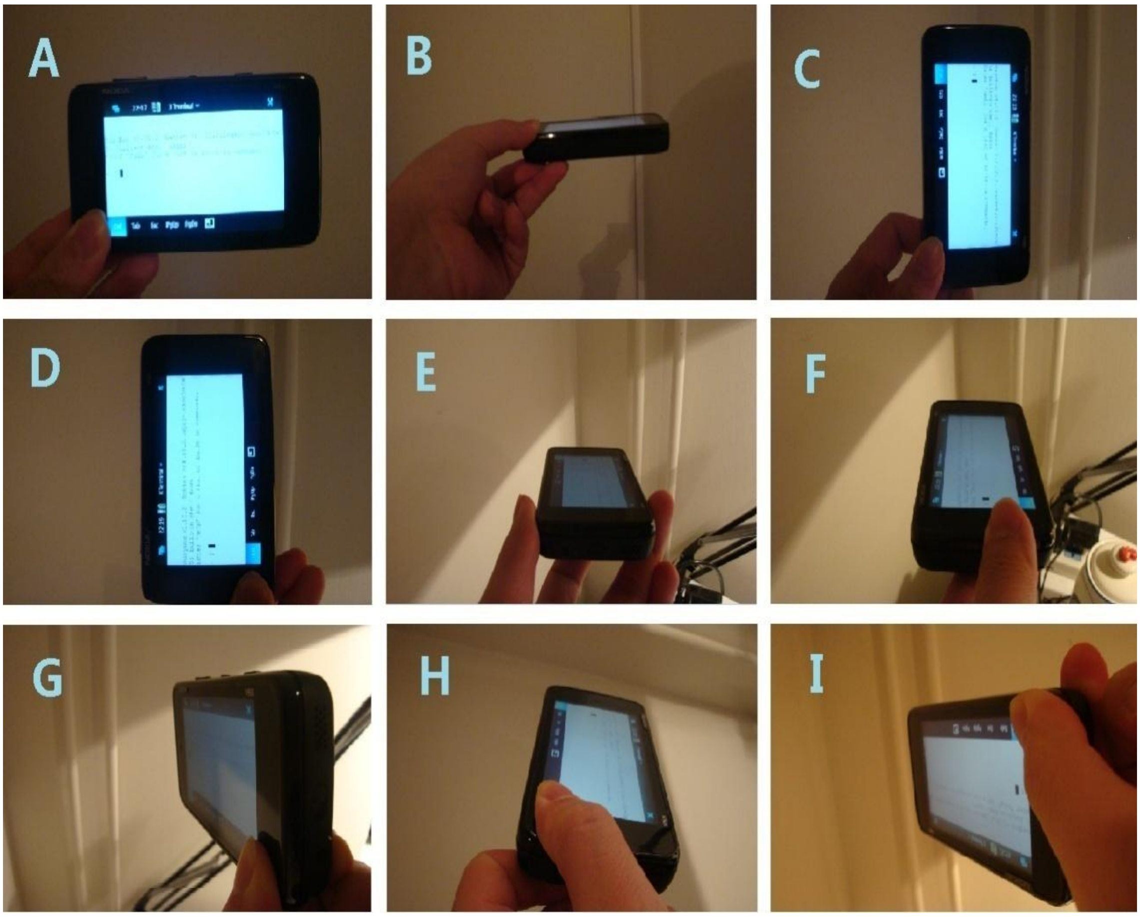

Figure 17 Device orientation experiments

The next table shows the results of different signal strength collected in the different orientations of the devices from Fig.16. For each distance measurements from 1meter to 5meters, the RSS measurements ranges are reported the standard deviation from 2.92 to 3.64. From the following table 8, we believe the RSS-to-Distance model we applied in our experiments is highly affected by the orientation of the devices. In our experiments, we always followed position A to make the results consistent.

Position	1m	3m	5m
A	-36	-42	-49
B	-37	-43	-47
C	-36	-49	-53
D	-38	-41	-48
E	-35	-43	-52
F	-43	-46	-56
G	-38	-46	-55
H	-39	-48	-53
I	-43	-52	-57
mean	-38.3	-45.6	-52.2
std	2.92	3.64	3.56

Table 8 Device orientations results

6 ANALYSIS OF THE RESULTS

This chapter mainly focuses on analysis of the results which get from the previous chapter and finalized with discussion on achieved results.

6.1 Three devices results

First of all, experiments with three devices have been carried out in this simple scenario: three MSs are placed around the user; the user tries to locate them with around movement action.

6.1.1 Experiment 1

Coordinates of each MS:

	X Axis	Y Axis
Ms1	-3	2
Ms2	3	2
Ms3	0	3

Table 9 Experiment 1 setups

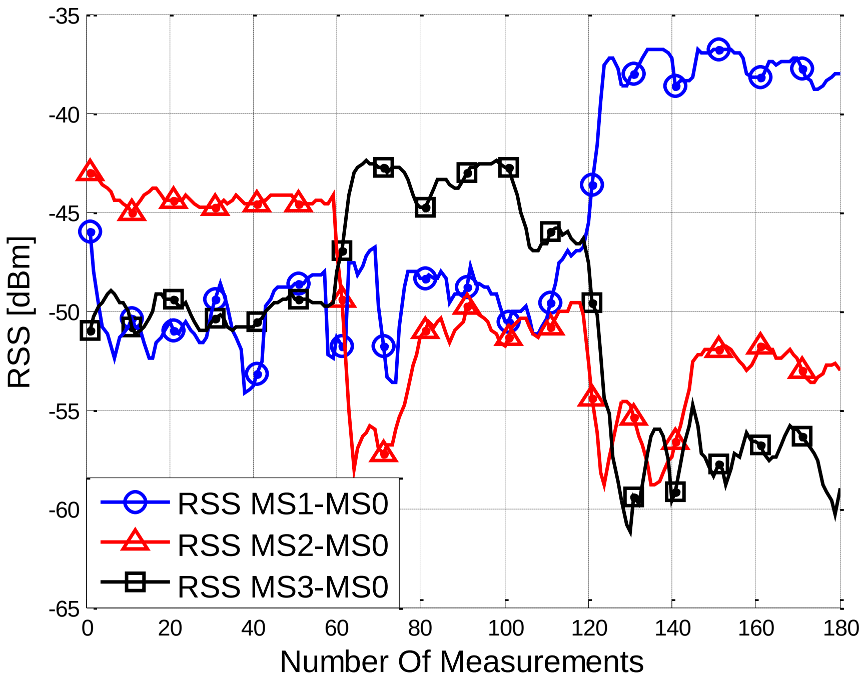

Figure 18 Experiment 1 RSS results

Figure 18 shows the behaviour of the RSS detected from MS0 whose coordinate is [0, 0] in three different time periods (about 60 records for each period). The trends of the signal show clearly and correctly how the signal strength performed in each period with respect to the different positions of receiver.

In the first period when RSS receiver is heading towards MS2, it receives the strongest signal strength against the rest of two MSs (MS1 and MS3). In the second period when the receiver is in the middle heading towards MS3, the black curve representing for signal strength from MS3 jumps on top above the ones belong to MS1 and MS2. The final part of the experiment indicates even more clearly as we expected MS1 (represented by the blue line) becomes the lead of three when the receiver is pointing to MS1 where MS0 has the shortest distance to MS1 among three MSs.

Figure 19 is the distance curve estimated based on the RSS information translating from empirical path-loss model. The lower the curve is the closer the distance between MSs is. According to the RSS measured before, we have detected the nearest device for each period in the order of MS2-MS3-MS1.

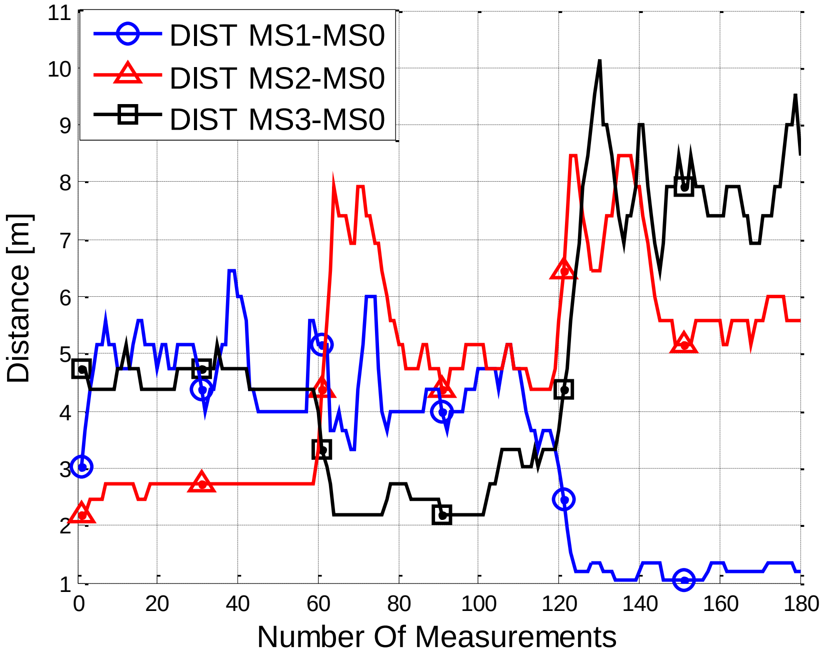

Figure 19 Experiment 1 distance results

In the following sector plot, Figure 20, all the estimated points in the entire 180 records are plotted by applying with least square algorithm. To enhance the view of relative position of the devices, the radar-look-like curves are drawn, hence, the relative positions could be clearly distinguished which potentially could be ported into a real application working on computer or mobiles.

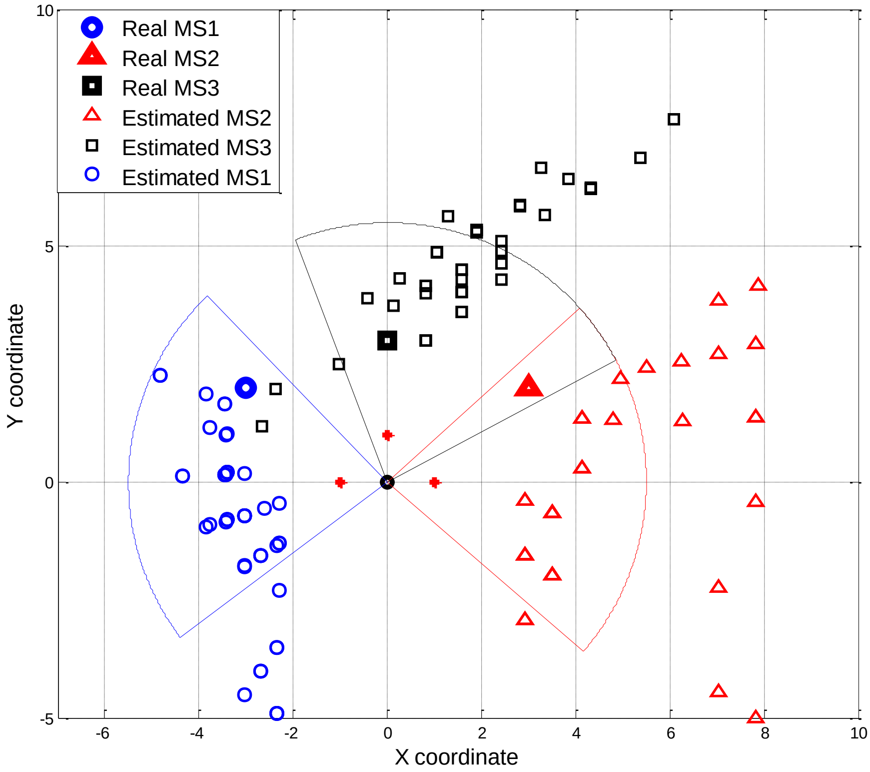

Figure 20 Experiment 1 sector plot

6.1.2 Experiment 2

	X Axis	Y Axis
Ms1	-2	6
Ms2	2	6
Ms3	0	7

Table 10 Experiment 2 setups

Comparing with the configuration of previous MSs, this one shows a more extreme case that the MSs to be detected are placed closer to each other and the distance between MSs and the centred MS are enlarged to 7 meters; in other words, this configuration represents a long and narrow case which could test the sensitivity of the algorithm whether it could still be applied or not.

Figure 21 is the signal strength behaviour. Due to long distance between MSs and receiver, the behaviours are now acting less reliable and clear. However a similar trend could still be detected from the picture. Take MS2, the red line as an example, it gets the highest point in the first period and a declining trend could be concluded from the picture which also agrees with previous experiment results. The behaviour of MS3, the black line, which is performing like low-high-low trends also makes us convinced the

RSS is correct. However, MS1 the blue one does not seem to behave as we expected; it gets the highest point in the second period which should be lower than the third period and higher than the first period.

Translating from path-loss model, the distance curves are shown in Figure 22. As we can see, the estimated distance fluctuates much more than the previous one when distance was closer to the receiver.

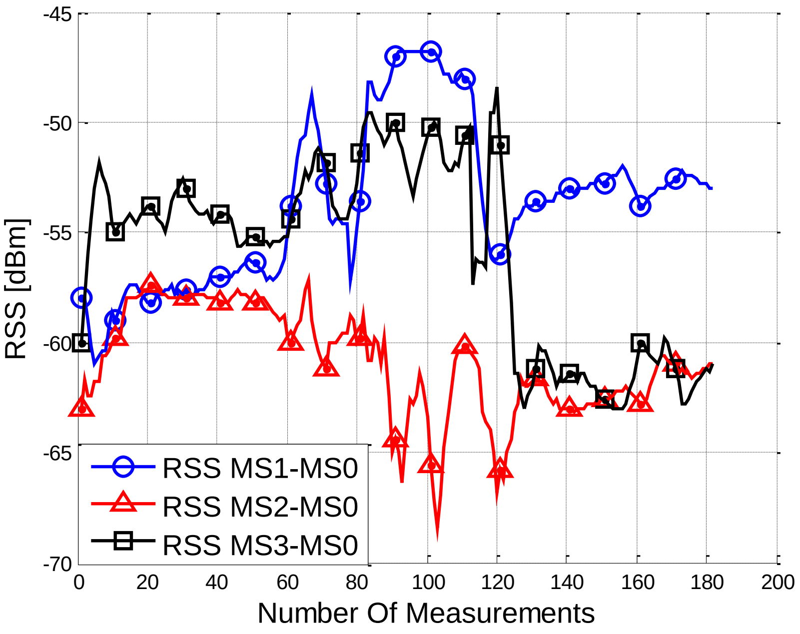

Figure 21 Experiment 2 RSS results

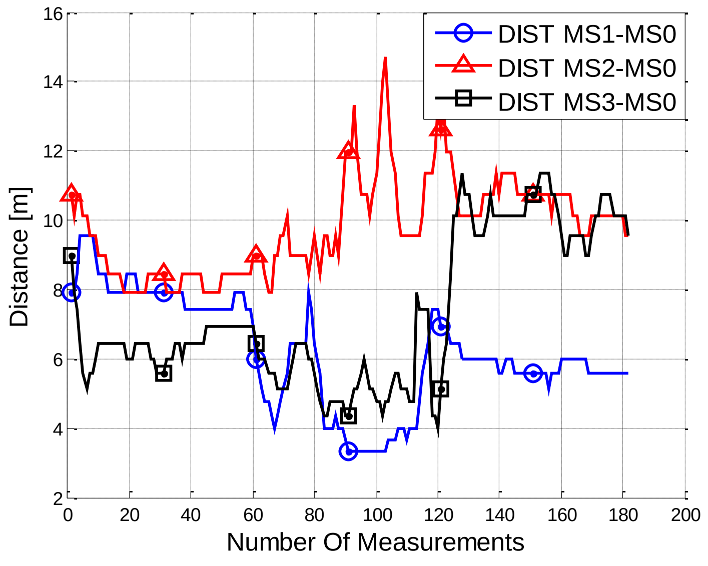

Figure 22 Experiment 2 distance results

It is hard to tell the exact preciseness from the signal strength graph (Figure 21) and distance graph (Figure 22), but when we have all the estimation spots in Figure 23, we could be sure that MS1 (blue) has been estimated just around the real position. The black spots for MS3 are not close to the real position but still they are estimated in a reasonable range. However, MS2 (red) spots are fully miss-estimated from the picture.

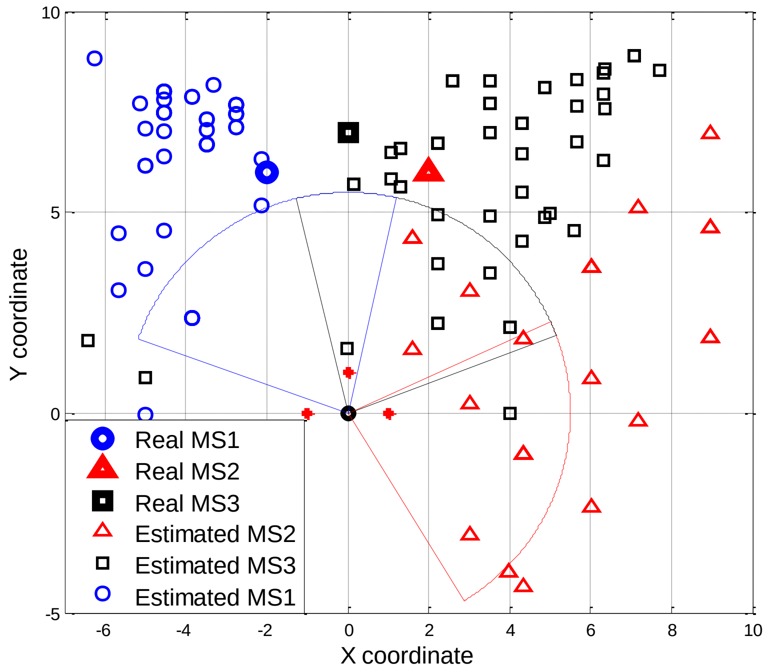

Figure 23 Experiment 2 sector plot

6.1.3 Experiment 3

An even worse case of experiment has been performed with the following configuration in the following table 11:

	X Axis	Y Axis
MS1	-3	12
MS2	3	12
MS3	0	13

Table 11 Experiment 3 setups

This configuration is characterized by a small distance between MS1 and MS2; but the distance between MS0 and those three MSs is the most extreme case in our experiments, up to 12-13 meters.

As a result, in Figure 24, coordinate plot is much more spread and unpredictable; a certain number of the spots of different devices have conflict in each others' range especially for the red ones standing for MS2 which totally miss-estimated. It is also hard to tell any result from the signal strength graph (Figure 25).

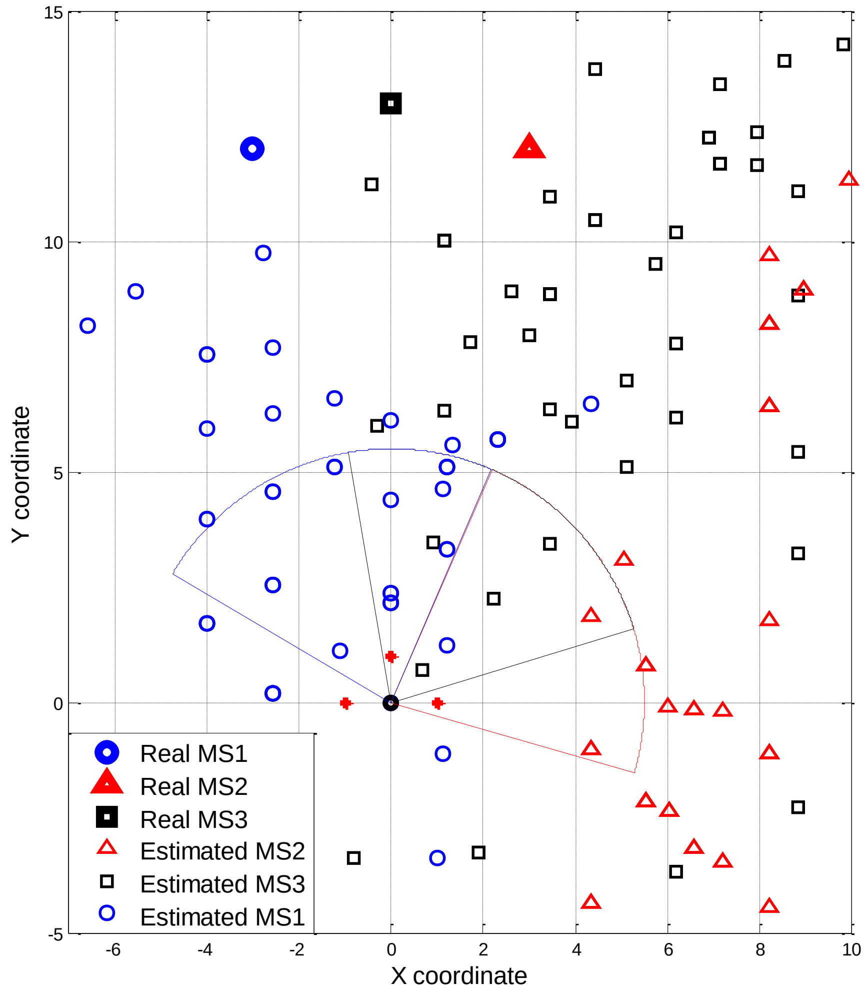

Figure 24 Experiment 3 sector plot

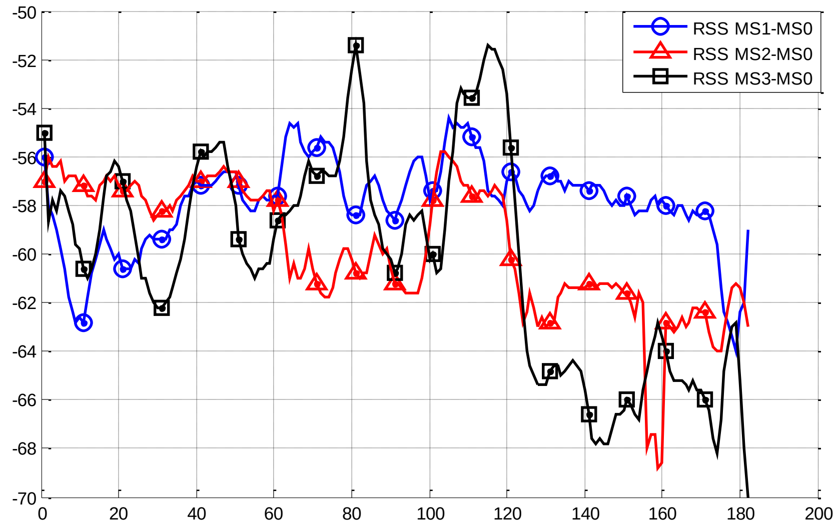

Figure 25 Experiment 3 RSS results

6.2 Five devices results

A more complex scenario with five different devices is carried out in the classroom environment with the following configuration in table 12.

	X Axis	Y Axis
MS1	-2	1
MS2	2	1
MS3	0	3
MS4	-1	2.5
MS5	1	2.5

Table 12 Five devices' coordinates

Our signal receiver is set in the centre with coordinates of [0, 0], for every 60 records it changes its orientation to a different device in the order of MS1 - MS4 - MS3 - MS4 - MS2.

Considering it is more complex than three devices shown previously, using four different type of mobile machine as mobile stations which would probably cause confusion in positioning estimation since they are using the same path-loss model but with independence power levels, the RSS might have some parts that are not easy and visible to interpret.

In Figure 26, the blue line for MS1 is higher in the first two periods than the rest; it implies that MS1 is near the place where MS0 is pointing at in the first two periods. The cyan line for MS4 dominates two periods after MS1, thus, it could be sure that MS4 is a neighbour of MS1. The black line for MS3 has two continuous high level parts in period

3 and 4 and the same as MS5 (green line), thus, these two MSs' places could be determined in period 3 and 4. The red line for MS2 has a rising trend and reaches the highest at the last period so that MS2 is located in the 5th period.

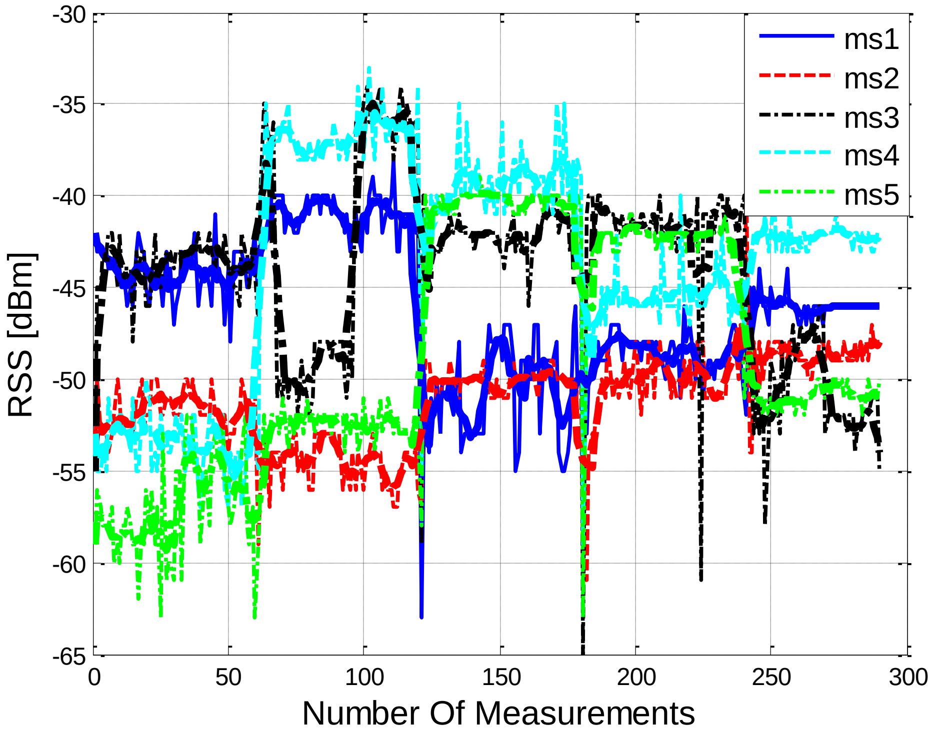

Figure 26 RSS measured for five devices

Figure 27 shows all the esitimated coordinates. As we expected though, there are some staggered places between MS4 and MS3, but it will not disturb us to distinguish their relative positions. Mean value of each coordinate is calculated and plotted on Figure 28. It is much easier to tell the positions from Figure 28.

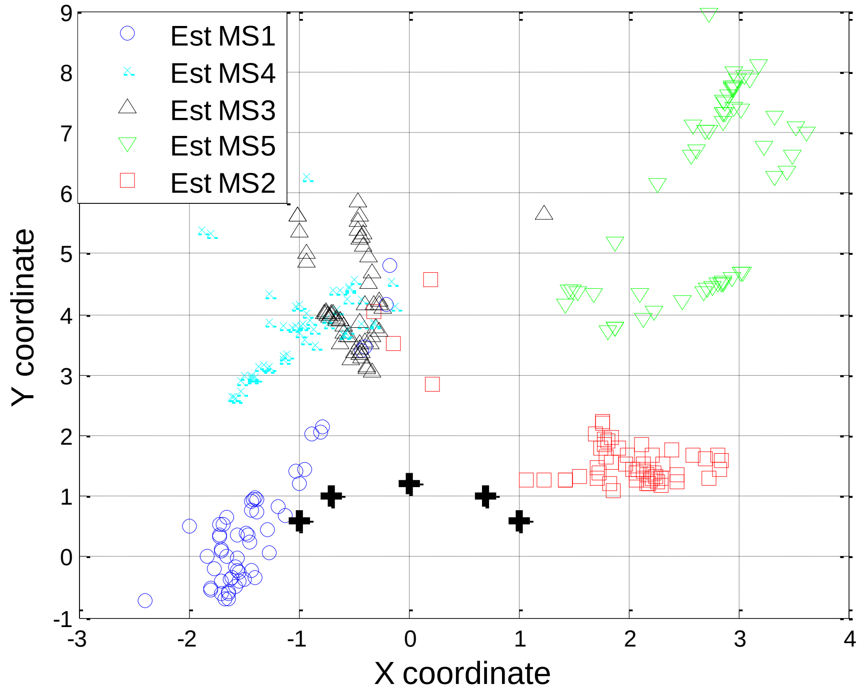

Figure 27 Five devices positions estimations

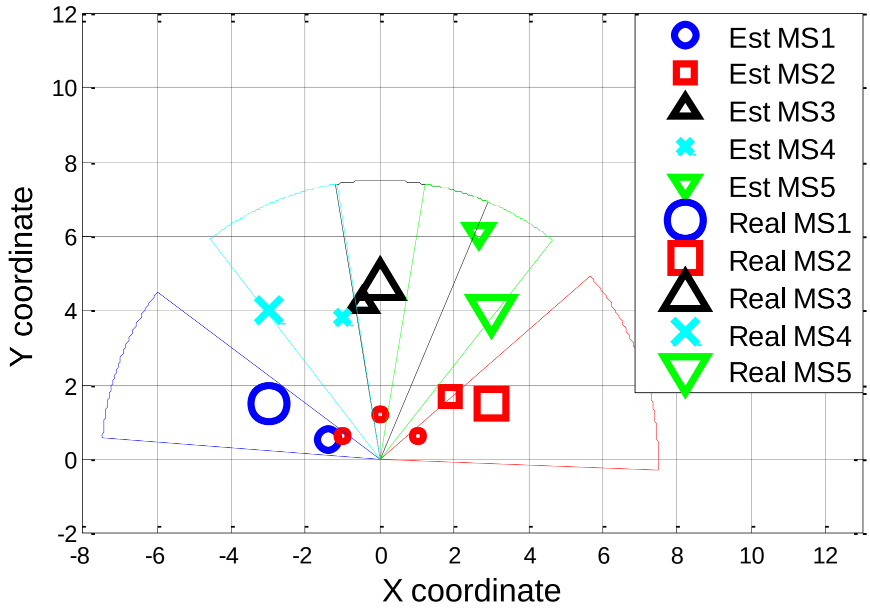

Figure 28 Five devices sector plot

6.3 Body-Loss results

6.3.1 Body blocking

The result in Figure 29 shows the RSS information in four different orientations between two MSs. On the left hand of Figure 29 is the signal strength curve while on the right hand is the distance in meters converting from the empirical RSS model. The blue line stands for front orientation which means no obstacle between two MSs, thus, it has precise distance estimation showing on Figure 29 right. A contrasting example of front orientation is the back orientation in black line which the receiver is fully blocked by human body. As we can see clearly from the picture, the signal strength jumps from -42dBm to -63dBm almost every 5 records and it leads estimated distance (Figure 29 right) to fluctuate a lot. The differences between the experiments of two sides are reasonable since the antenna is on one side of the mobile device. In our cases the signal strength seems not be influenced on the left side but has a similar behaviour with the back side on the right side.

Summing up, signal strength is highly affected by human body especially when the antenna is fully covered in the back case.

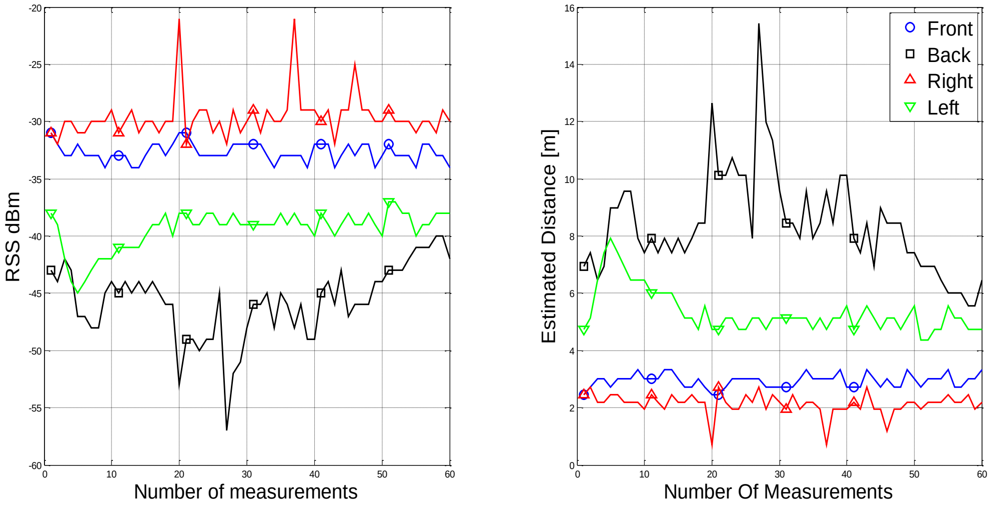

Figure 29 Body blocking results

6.3.2 Hand grip effect

In hand gripping experiments, the results are indicating the effects caused by hand-grip. In Figure 30, the left one shows how the signal strength is fluctuated between two cases while the right one demonstrates the huge difference in distance view. Both of the blue lines represent for no hand gripping illustrate a smooth performance; on the other hand, the red lines represent for hand gripping effect fluctuate a lot.

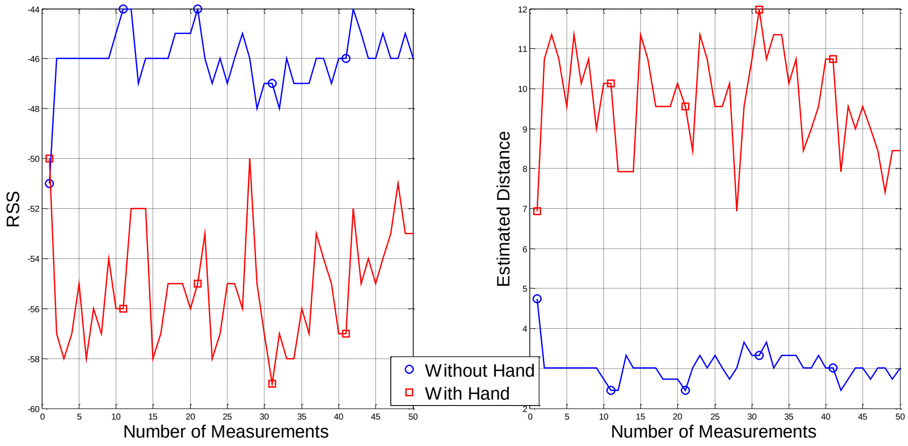

Figure 30 Hand grip effect results

6.4 Long distance Vs. Short distance

In Figure 31, the square symbols are the real positions of the device at the distance of 3 meters to 13 meters from MS0. The plus symbols indicate the average value of the estimated coordinates. The error between real and estimated coordinates is extended when the measuring distance becomes longer especially in case of 11 meter and 13 meters.

It is more convinced and clear that in Figure 32, the spots estimated at 11 meters and 13 meters away from MS0 are plotted much more irrational then the ones measured in short distance.

Figure 32 is clearer when all the estimated spots have been plotted. In the short range such as the red and the blue for 3 and 5 meters, positions are estimated around the real position. The long range spots (the black and cyan) are estimated more spread from the real position. Figure 33 shows the Cumulative Distribution Function (CDF) of the Root Mean Squared Error (RMSE) of the aforementioned effect.

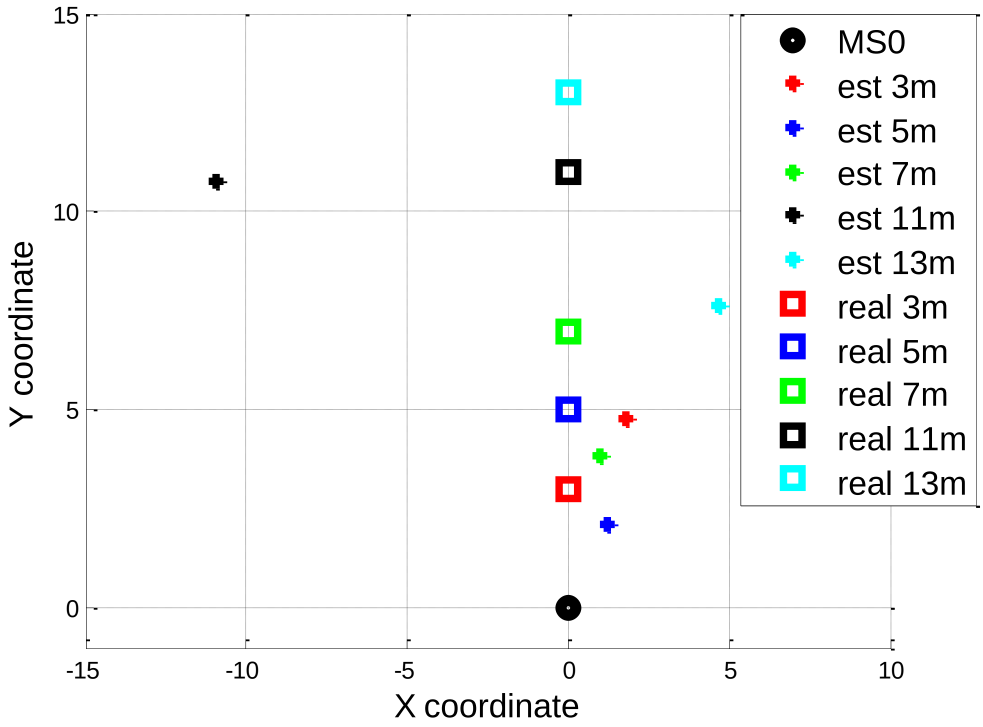

Figure 31

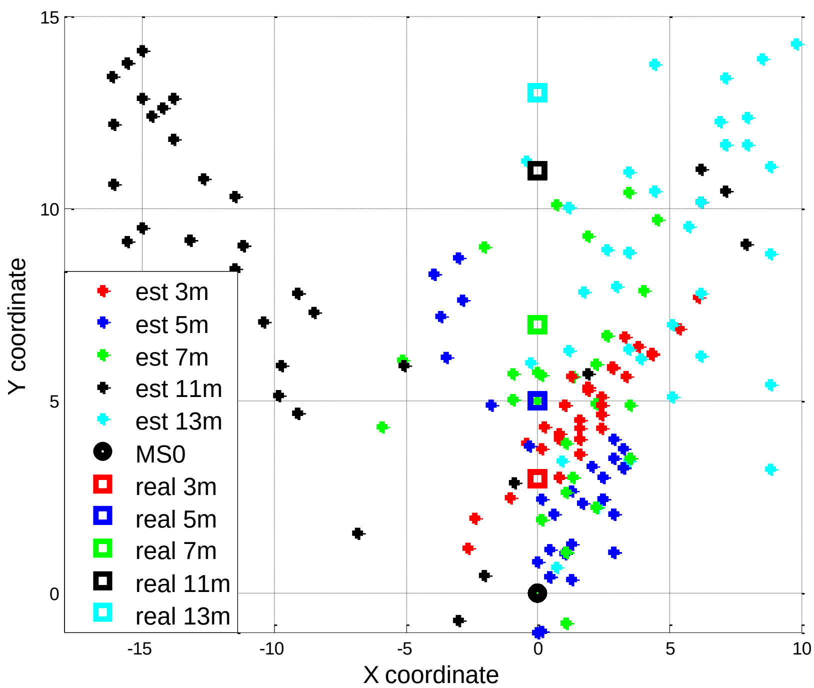

Figure 32 Estimated positions varying the distance between MS3 and MS0

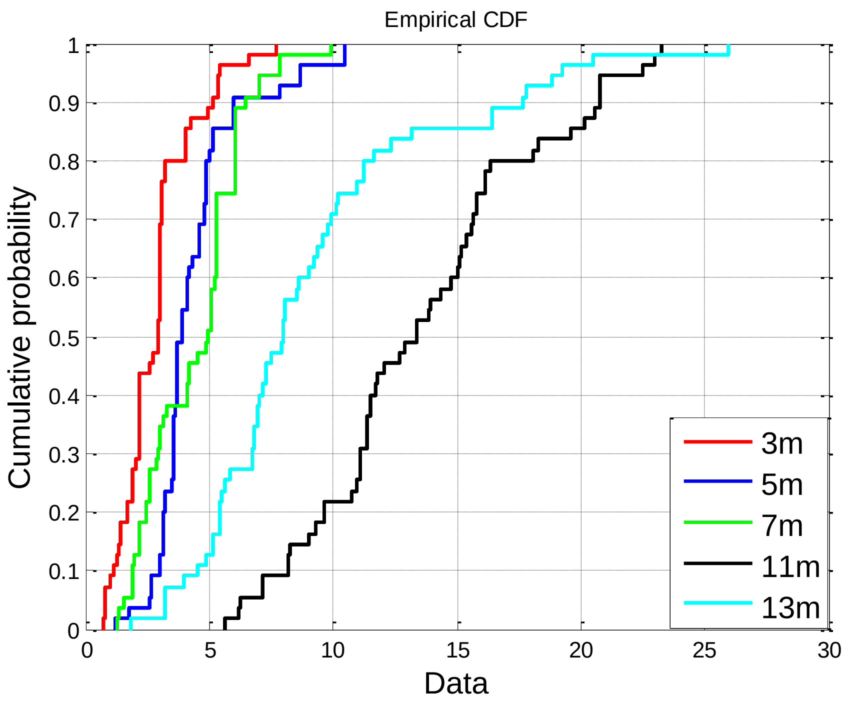

Figure 33 CDF of the Error of the Estimated Positions in terms of Distance from the Real positions

It is also compared with two scenarios in Figure 34 which apparently indicates that the RSS is more reliable and predictable in the short range (blue curve) than the long range one.

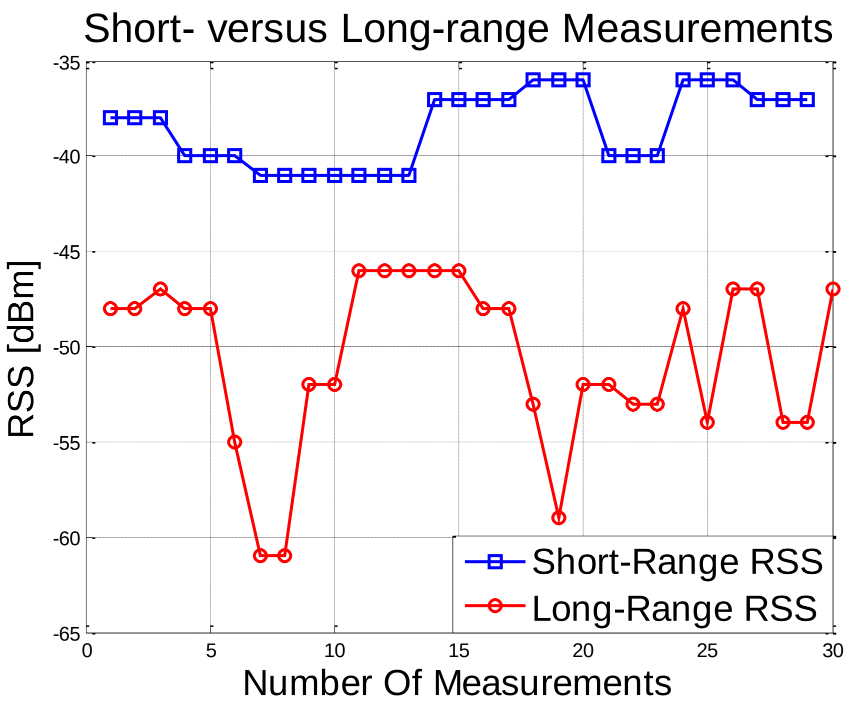

Figure 34 Short range vs. long range

The short range measurements are collected in a close distance about 2 meters while the long range measurements are done at about 15 meters. From the results, we found that the RSS is more reliable in close range if compared with the long distance case. The standard deviations in two scenarios are 1.99 vs. 4.43.

7 CONCLUSION

In this thesis, we have proposed a practical solution based on RSS measurements to locate nearby mass market devices connected in ad-hoc network.

Empirical path-loss curves have been made by experiments with different devices for signal strength to distance mapping. A number of experiments with various configurations has been carried out to observe and analysis the behaviour in different scenarios. A least square algorithm has been applied in the analysis of those experiments. A python based practical application has been implemented on Linux-based device.

Results of the proposed relative positioning technique show the feasibility and accuracy of the algorithm. We have demonstrated successful experiments to locate up to five heterogeneous devices in short range. However the results also indicate the accuracy is getting poor when the distance increases. We have also demonstrated device orientation factor and human body impairments. The python application shows a potential chance to have future works on developing interesting applications based on this relative positioning technique.

8 APPENDIX

Code for least square algorithm in Matlab

```
function    result = lsli(r1,r2,r3,r4,r5)

% reference stations coordinates
x2 = -1;
y2 = 0.6;
x3 = -0.7;
y3 = 1;
x4 = 0;
y4 = 1.2;
x5 = 0.7;
y5 = 1;
x6 = 1;
y6 = 0.6;

% estimated distance from five different APs
r21=r1;
r31=r2;
r41=r3;
r51=r4;
r61=r5;

% Equations
K2=x2^2+y2^2;
K3=x3^2+y3^2;
K4=x4^2+y4^2;
K5=x5^2+y5^2;
K6=x6^2+y6^2;

H=[x2 y2 r21;x3 y3 r31;x4 y4 r41;x5 y5 r51;y6 y6 r61];
d=-(1/2)*[r21^2-K2;r31^2-K3;r41^2-K4;r51^2-K5;r61^2-K6];
X=inv(H'*H)*H'*d;

% X[1]:estimated x coordinate
% X[2]:estimated y coordinate
result=[X(1), X(2];

end
```

9 BIBLOGRAPHY

[1] K. Kalliola, “Bring Navigation Indoors”: http://www.nokia.com/NOKIA_COM_1/Press/Press_Events/The_Way_We_Live_Next_2008/presentations/TWWLN08_Kimmo_Kalliola.pdf

[2] M.S. Corson, J.P. Macker,G.H Cirincione, “Internet-based mobile ad hoc networking”, Internet Computing, IEEE, vol. 3, issure.4, pp 63-70, Jul/Aug. 1999

[3] D. Perkins, R. Tumati, H.Wu, I. Ajbar, “Localization in Wireless Ad Hoc Networks”, in Resource Management in Wireless Networking,Springer US, vol. 16, July 2006, pp. 507 – 542.

[4] M. Hazas, C. Kray, H. Gellersen, H. Agbota, G. Kortuem, and A. Krohn, “A relative positioning system for co-located mobile devices,” in MobiSys ’05: Proceedings of the 3rd international conference on Mobile systems, applications, and services. New York, NY, USA: ACM Press, 2005, pp. 177–190.

[5] TWIN: local communities on adhoc wlan:

http:// www.tkt.cs.tut.fi/research/daci/twin_overview.html

[6] H. Liu, H. Darabi, P. Banerjee, and J. Liu, “Survey of wireless indoor positioning techniques and systems,” IEEE Trans. Syst., Man, Cybern. C: Applications and Reviews, vol. 37, no. 6, pp. 1067–1080, Nov. 2007.

[7] J. Hightower and G. Borriello, “Location Systems for Ubiquitous Computing,” Computer, vol. 34, no. 8, Aug. 2001, pp. 57–66.

[8] F. Della Rosa, H. Leppäkoski, A. Ghalib, L. Ghazanfari, O. Garcia, S. Frattasi and J. Nurmi “Ad Hoc Networks for Cooperative Mobile Positioning”, in Mobile Ad-Hoc Networks: Applications, January 2011

[9] M. Aatique, MASTER THESIS, Evaluation Of Tdoa Techniques For Position Location In CDMA Systems. Virginia Polytechnic Institute and State University, September 1997

[10] A. H. Sayed, A. Tarighat, and N. Khajehnouri, “NetworkBased Wireless Location,” IEEE Signal Processing Magazine, vol. 22, no. 4, pp. 24–40, July 2005.

[11] A. Mordechai, D. Hertz, Time Delay Estimation by Generalized Cross Correlation Methods, IEEE TRANSACTIONS on acoustics, speech, and signal processing, VOL. ASSP-32, NO. 2, APRIL 1984.

[12] Y. Zhao, “Standardization of mobile phone positioning for 3G systems,” IEEE Commun. Mag., vol. 40, no. 7, pp. 108–116, Jul. 2002

[13] A.W.S. Au, MASTER THESIS. RSS-based WLAN Indoor Positioning and Tracking System Using Compressive Sensing and Its Implementation on Mobile Devices. University of Toronto, 2010

[14] A. Savvides, C. Han, M. Srivastava, Dynamic fi D-grained localization in ad-hoc networks of sensors, Proceedings of ACM MobiCom’01, Rome, Italy, July 2001, pp. 166–179.

[15] X. Li and K. Pahlavan, “Super-resolution TOA estimation with diversity for indoor

geolocation,” IEEE Transactions on Wireless Communications, vol. 3, no. 1, pp. 224–234, 2004.

[16] D. Li, K. Wong, Y.H. Hu, A. Sayeed. "Detection, Classification and Tracking of Targets in Distributed Sensor Networks", IEEE Signal Processing Magazine, Volume: 19 Issue: 2, Mar 2002.

[17] K.W. Cheung, H.C. So, W.K. Ma, and Y.T. Chan, “Least squares algorithms for time-of-arrival-based mobile location,” IEEE Trans. Signal Processing, vol. 52, no. 4, pp. 1121–1130, Apr. 2004.

[18] J. Caffery and G. L. Stuber, “Subscriber location in CDMA cellular networks,” IEEE Trans. Veh. Technol., vol. 47, pp. 406–416, May 1998.

[19] M. A. Spirito, “On the accuracy of cellular mobile station location estimation,” IEEE Trans. Veh. Technol., vol. 50, pp. 674–685, May 2001.

[20] D. J. Torrieri, “Statistical theory of passive location systems,” IEEETrans. Aerosp. Electron. Syst., vol. AES-20, pp. 183–197, Mar. 1984.

[21] C. L. F. Mayorga, F. della Rosa, S. A. Wardana, G. Simone, M. C. N. Raynal, J. Figueiras, and S.Frattasi, “Cooperative Positioning Techniques for Mobile Localization in 4G Cellular Networks,”Proceedings of the IEEE International Conference on Pervasive Services, July 2007.

[22] Least Squares: http://www.mathworks.com/moler/leastsquares.pdf

[23] A. Bahillo, S. Mazuelas, R. M. Lorenzo, P. Fernández, J. Prieto, R. J. Durán, E. J. Abril, “Hybrid RSS-RTT Localization Scheme for Indoor Wireless Networks”, Mar.2010.

[24] P. Krishnan, A. S. Krishnakumar, W.-H. Ju, C. Mallows, and S. Ganu, “A system for LEASE: location estimation assisted by stationary emitters for indoor RF wireless networks,” in Proceedings of the Joint Conference of the IEEE Computer and Communications Societies (INFOCOM '04), vol. 2, pp. 1001–1011, March 2004.

[25] H. Hashemi, “The indoor radio propagation channel,” Proceedings of the IEEE, vol. 81, no. 7, pp. 943–968, 1993.

[26] L. Heikki, J. Suvi, L. Timo, K. Risto, and L. Jaakko, “Experimental evaluation of location methods based on signal-strength measurements,” IEEE Transactions on Vehicular Technology, vol. 56, no. 1, pp. 287–296, 2007.

[27] Y. Qi, Wireless geolocation in a non-line-of-sight environment, Ph.D. dissertation, Princeton University Press, Princeton, NJ, USA, November 2003.

[28] D. Niculescu and B. Nath, “DV based positioning in ad hocnetworks,” Telecommunication Systems, Baltzer, vol. 1, 2003, toappea.

[29] L.E. Holmquist, J. Falk, J. Wigström Supporting Group Collaboration with Inter-Personal Awareness Devices. Journal of Personal Technologies, 3(1-2), Springer, 1999.

[30] Krumm J, and Hinckley The NearMe wireless proximity server. In Proceedings of Ubicomp: Ubiquitous Computing (Nottingham, UK, Sept. 2004), Springer, pp. 283–300

[31] BlueHoo: http://Bluehoo.com/

[32] RELATE: Relative Positioning of Mobile Objects in Ad hoc Networks http://eis.comp.lancs.ac.uk/?id=16

[33] N. Banerjee, S. Agarwal, P. Bahl, R. Chandra A. Wolman, and M. Corner "Virtual Compass: Relative Positioning to SenseMobile Social Interactions" Microsoft Technical Report, MSRTR-2010-5, January 2010.

[34] C. Peng, G. Shen, Y. Zhang, Y. Li, K. Tan,: Beep Beep: A High Accuracy Acoustic Ranging System Using COTS Mobile Devices. In: SenSys (2007).

[35] C.-K. Toh, Ad Hoc Mobile Wireless Networks: Protocols and Systems. Prentice Hall PTR, 2001.

[36] K. Pahlavan and A. Levesque, Wireless Information Networks. NewYork: Wiley, 1995.

[37] F. Della Rosa, H. Leppäkoski, S. Biancullo, J. Nurmi, "Ad-hoc networks aiding indoor calibrations of heterogeneous devices for Fingerprinting applications", IPIN, Zurich, Sep.2010.

[38] F. Della Rosa, L. Xu, J. Nurmi, M. Pelosi, C. Laoudias, A. Terrezza, "Hand-Grip and Body-Loss Impact on RSS Measurements for Localization of Mass Market Devices". International Conference on Localization and GNSS (ICL-GNSS 2011), Tampere Finland. 2011.

[39] F. Della Rosa, L. Xu, H. Leppäkoski, J. Nurmi "Relative Positioning of Mass Market Devices in Ad-hoc Networks" Proceedings of 2011 International Conference on Indoor Positioning and Indoor Navigation (IPIN), 21-23 September, Guimarães, Portugal, 2011.

[40] P. Bahl and V.N. Padmanabhan, RADAR: An in-building RF-based user location and tracking system. In Proceedings of IEEE INFO-COM, volume 2, pages 775{784, March 2000.

[41] C. Wong, Klukas, R. & Messier, G.G. (2008). Using WLAN Infrastructure for Angle-ofArrival Indoor User Location, 68th Semi-Annual IEEE Vehicular Technology Conference, 2008. VTC 2008-Fall, pp. 1-5, Calgary, BC, Sept. 2008, IEEE

[42] C. M. Wong, R. Klukas, and G. G. Messier. Using WLAN infrastructure for angle-of-arrival indoor user location. In Proc. of the IEEE VTC Conf., pages 1{5, Sept. 2008.

[43] X. Li, "RSS-based location estimation with unknown pathloss model,"IEEE Trans. Wireless Commun., vol. 5, no. 12, pp. 3626–3633, Dec. 2006.

[44] Pygame: http://pygame.org/

[45] Numpy: http://numpy.scipy.org/